BB-REG-NET

Persistent Plastic Pollution and Ecotoxicology

The role of biodegradable plastics

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Working Group: Circular Bioeconomy

Report Reference: Ecotoxicology

Date: February 2026

Version: 1.4

Classification: Public

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Executive Summary

In 2021, the UK Government acknowledged that bio-based and biodegradable plastics have the potential to address plastic waste and emphasised the need for strong standards and certification schemes to verify benefits and avoid any unforeseen environmental harms. The government was keen to avoid any unintended consequences, including whether biodegradable plastics might accelerate the creation of microplastics, and or associated ecotoxicity.

This was the topic of a previous BB-REG-NET report *'Addressing Persistent Plastic Pollution: The Case for Biodegradable Solutions'* where it was clearly demonstrated that, whilst bio-based and biodegradable plastics can result in the formation of microplastics, they are transient and are actually key in preventing long-term microplastic accumulation[1].

In parallel to concerns around microplastics formation, the UK government has expressed concerns about the ecotoxicological effects that microplastics can have, including those that may originate from bio-based and biodegradable materials.

Due to their size and other physico-chemical properties, microplastics *per se* have the potential to impact the environment. They can spread through air, water, and soil and be ingested or absorbed by living organisms in both aquatic and terrestrial environments. This affects physiological and biochemical processes by impacting feeding rates, growth, reproduction, and immune function. Additionally, chemicals other than the polymers used in making plastics can leach from microplastics (such as BPA and phthalates) and are also implicated in environmental health impacts. Furthermore, microplastics can act as a vector for hazardous chemicals such as heavy metals and persistent organic pollutants, which may accumulate in organisms and be transmitted along the food chain. This can occur through three key mechanisms: hydrophobic interactions, electrostatic interactions, and pore filling.

These negative effects are a potential factor of microplastics from all material origins and with all levels of degradative ability, whether conventional, bio-based or biodegradable. Whilst this implies that biodegradable microplastics could produce ecotoxic effects, this presents an incomplete representation of the situation as, crucially, behaviour of biodegradable microplastics in the environment differ significantly from that of conventional plastics. As discussed extensively in the earlier BB-REG-NET report[1], biodegradable microplastics are transient and typically less persistent, allowing further decomposition as part of a continuum towards complete microbial degradation – with biodegradable microplastics ultimately being converted into biomass and carbon dioxide. Depending on the environment, full biodegradation can vary in time, particularly in low-temperature, low-oxygen, or nutrient-poor environments (such as in the marine environment). However, and importantly, microplastics from conventional non-biodegradable plastics, will not undergo mineralisation and will continue to persist in the environment.

Ecotoxicological endpoints are central to assessing the environmental impacts of plastics and represent the measurable biological effects that exposure to a substance can cause in living organisms. They include measuring changes in biomarkers or examining the direct effects of these changes on growth inhibition, impaired reproduction, developmental abnormalities, behavioural changes, and mortality. Measurements are typically made in controlled laboratory or glasshouse conditions and can use representative species from different parts of the ecosystem, such as microorganisms, algae, invertebrates and fish. By examining how biomarkers or whole organisms respond to varying concentrations of degradation products or additives released from plastics, thresholds at which harmful effects begin to occur can be determined.

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[1] BB-REG-NET (2025) Addressing persistent plastic pollution: the case for biodegradable solutions

Importantly, ecotoxicological endpoints do not only capture acute toxicity (short-term lethal effects), but also chronic and sub-lethal impacts that may affect long-term population stability and ecosystem functioning. For example, reduced reproductive success or slowed growth can significantly alter food webs, biodiversity and ecological resilience over time. Together, these endpoints provide critical evidence for evaluating whether plastics — and the substances they release during breakdown — are environmentally safe under realistic conditions of use and disposal.

These endpoints are embedded within established regulatory frameworks and standards that ensure that certified materials meet defined environmental safety and biodegradability criteria and give confidence to the public as well and industry. Compliance with ecotoxicological testing requirements is a determining factor for market approval and the responsible use of all plastics, and this includes biodegradable plastics as well.

This report examines two key regulatory domains — the European standards for industrial compostable packaging (EN 13432:2000) and biodegradable mulch films used in soil applications (EN 17033:2018) — and explains how these frameworks embed ecotoxicological safeguards to enable the safe and sustainable market adoption of biodegradable products.

Both standards, developed under the framework of the European Committee for Standardization, established scientifically defined testing requirements to ensure that materials marketed as biodegradable do not cause harm to the environments in which they are intended to break down. They require evidence not only of physical disintegration and biodegradation, but also of biological safety following degradation.

In practice, this means that materials must undergo ecotoxicological testing to demonstrate that their breakdown products do not adversely affect key organisms such as plants, soil invertebrates or microbial communities. For example, compost quality tests assess whether residues inhibit plant growth, while soil exposure tests evaluate impacts on organism health and ecosystem function. These assessments ensure that biodegradation does not result in harmful accumulation of toxic intermediates or persistent residues.

By integrating ecotoxicological endpoints directly into certification criteria, these standards move beyond simple “ability to biodegrade” and instead verify environmental compatibility under realistic end-of-life conditions. This helps regulators, manufacturers and users ensure that biodegradable products perform their intended function without compromising soil health, compost quality or broader ecosystem integrity — thereby supporting responsible innovation and public confidence in biodegradable plastics.

Contents

1 Introduction

Plastics are indispensable to modern life, yet their widespread use, improper disposal and persistence have led to environmental accumulation to the extent that plastic pollution is widely considered one of the most serious environmental challenges this century[2].

Microplastics (defined as being fragments less than 5mm) may originate primarily as particles intentionally produced for industrial or consumer use, or as secondary fragments derived from the degradation of larger plastic items. They have been detected in marine, freshwater, soil, and atmospheric compartments giving potential for long-range transport and bioaccumulation even in remote parts of the world and in deep sea areas [2, 3]. Persistence, mobility, and toxicity threaten ecosystem stability by altering food web dynamics, impairing nutrient cycling, and diminishing resilience.

Microplastics and ecotoxicology

Ecotoxicologically microplastics pose complex and system-wide risks to the biotic and abiotic components of ecosystems through three avenues:

- as physical stressors themselves,
- through the release of other chemicals used in the manufacture of the plastic such as plasticisers,
- as chemical vectors for other hazardous substances, such as persistent organic pollutants, heavy metals, and pathogens[4].

Regardless of their source, microplastics can increase the production of reactive oxygen species (ROS) —highly reactive oxygen-containing molecules that are naturally produced in cells during metabolism – in living organisms. When present in excess, these molecules can damage cellular components. As a result, increased ROS levels can lead to oxidative stress, DNA damage, and genotoxic effects, as well as disruptions in metabolic processes and organ function in both mammalian and aquatic models[5, 6, 7, 8]. Effects are often dependent on dose and particle properties (polymer type, size, shape, weathering, and sorbed contaminants). Further, detailed mechanistic work and targeted animal studies show that these outcomes follow a dose-dependent pattern [7,9], with higher concentrations or longer exposure durations of microplastics leading to greater oxidative damage, more pronounced genotoxicity, and stronger alterations in gene expression related to metabolism and stress responses.

At the same time, interpreting these findings for environmental risk assessment remains challenging. Differences in experimental models, particle properties, and methodological approaches contribute to variability between studies, and many laboratory experiments employ concentrations that exceed those typically observed in natural environments. Consequently, while microplastics clearly have the capacity to interact with contaminants—due in part to their high surface area-to-volume ratio and ability to adsorb chemicals—the ecological significance of these

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[2] Li et al (2023) Potential health impact of microplastics: a review of environmental distribution, human exposure, and toxic effects *Environment and Health* 1:4

[3] Bergman et al (2017) High Quantities of microplastic in Arctic deep-sea sediments from the HAUSGARTEN observatory *Environmental Science and Technology* 51 (19) 11000:11010

[4] Wright & Kelly (2017) Plastic and human health: a micro issue? *Environmental Science & Technology* 51(12) 6634–6647

[5] Osman et al (2023) Microplastic sources, formation, toxicity and remediation: a review *Environmental Chemical Letters* 4: 1-41

[6] Sangkham et al (2022) A review on microplastics and nanoplastics in the environment: their occurrence, exposure routes, toxic studies, and potential effects on human health *Marine Pollution Bulletin* 181 (113832)

[7] Kadac-Czapska et al Microplastics and oxidative stress – current problems and prospects *Antioxidants* 8(13): 529

[8] Panizzolo et al (2023) Biomarkers of oxidative stress, inflammation, and genotoxicity to assess exposure to micro- and nanoplastics. A literature review *Ecotoxicology and Environmental Safety* 267: 115645

[9] Majeed and Rabee (2025) The toxicity of polyethylene microplastics on molecular and biochemical parameters in albino mice *Journal of Ecological engineering* 26(3) 274-282

interactions under realistic environmental conditions remains an area of ongoing research[10]. Within this context, existing standards and certification schemes aim to manage the manufacture and use of plastics and associated additives, and current evidence suggests that when materials comply with these frameworks, risks are generally considered manageable.

In addition to the polymer itself and how it behaves, plastics also include additives which contribute to toxicity once released[11]. This includes plasticisers, stabilisers and antioxidants, flame retardants, colorants and fillers, as well as unreacted monomers and oligomers, all of which may leach during degradation and contribute to ecotoxic effects.

Biodegradable microplastics

Concern over microplastics has driven research and policy initiatives aimed at developing alternative materials that minimise environmental burden while maintaining the functional performance modern life demands of plastic materials. Among these, biodegradable plastics have emerged as a promising solution: these materials are designed to undergo microbial decomposition under suitable conditions, transforming into carbon dioxide, water, and biomass (Figure 1).

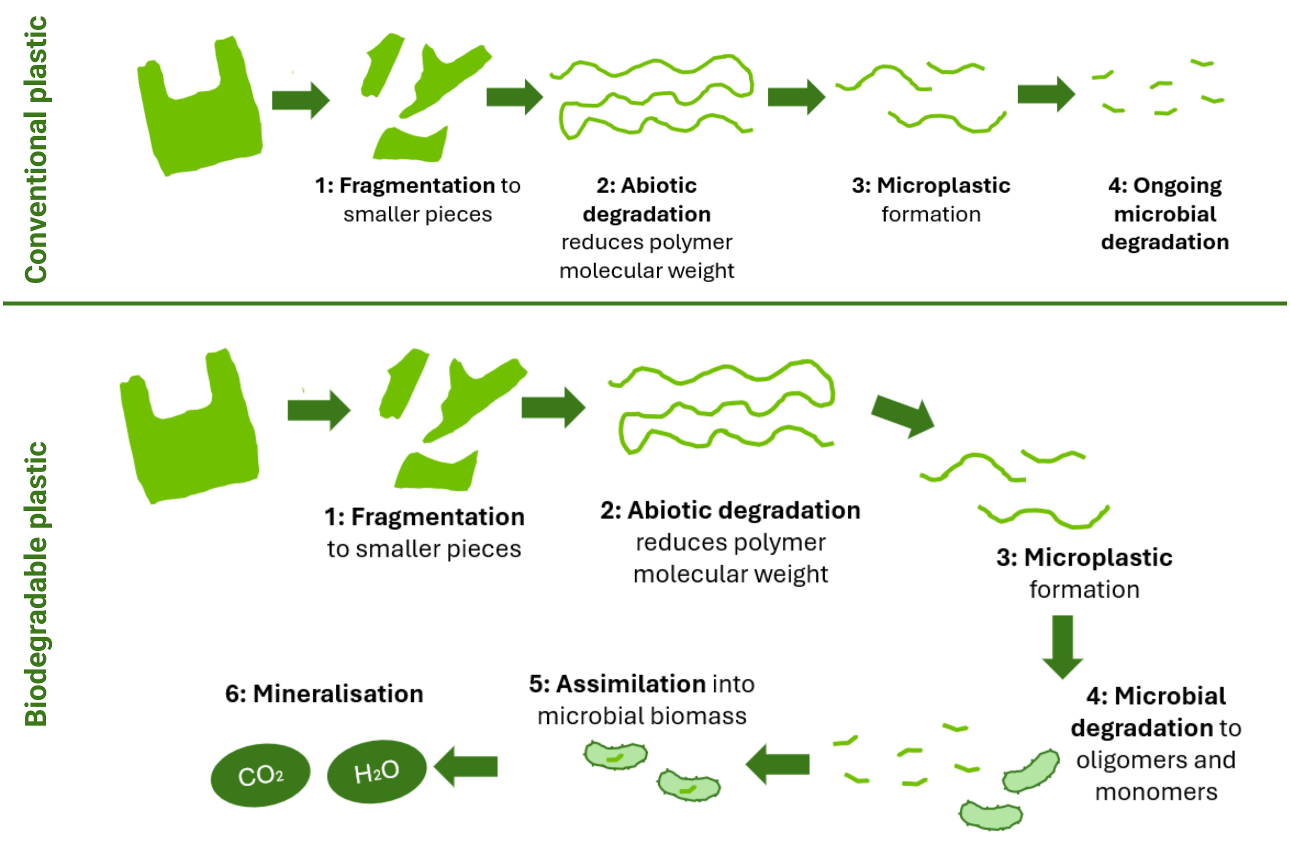

Figure 1 : Simplified process of plastic degradation (top) and biodegradable plastic degradation (bottom)[1]

Compared with conventional polymers, biodegradable plastics could substantially reduce long-term ecological persistence, thereby potentially limiting the formation of permanent microplastic residues in soils, aquatic and other ecological and living systems.

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[10] Galloway et al (2017) Interactions of microplastic debris throughout the marine ecosystem *Nature Ecology and Evolution 1: 0166*

[11] Courtene-Jones et al (2023) A review of biodegradable plastics from multidisciplinary perspectives

2 Ecotoxicological factors of microplastics in the open environment

This section briefly reviews the ecotoxicological impact of microplastics *per se* on the environment.

2.1 Mechanism of microplastic action

Microplastics create a vast, growing 'microplastisphere'[12] that can adsorb many organic pollutants, although it is challenging to predict what will adsorb and the rate of adsorption**Error! Bookmark not defined.**. Microplastics *per se* carry pollutants primarily through three main mechanisms: hydrophobic interactions, electrostatic interactions, and pore filling (Figure 2):

- Hydrophobic interactions arise as many microplastics and organic pollutants are water-repellent, causing them to naturally attract one another in aquatic environments. Hydrophobicity is important, but not sufficient alone to explain adsorption behaviour across polymers and water chemistries.
- Electrostatic interactions occur when microplastics and contaminants possess opposite electrical charges, drawing them together on the particle surfaces.
- Pore filling happens when microplastics, especially those weathered with cracks and pores, physically trap pollutant molecules within their structure.

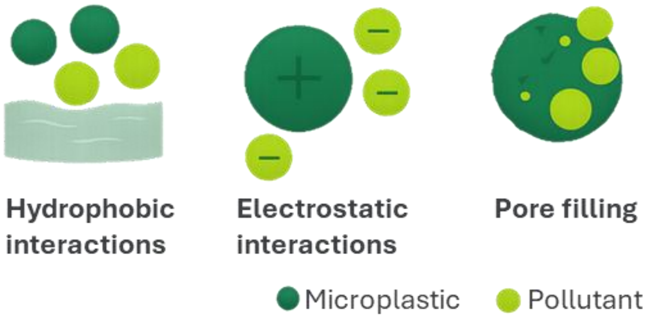

Figure 2 : Mechanisms by which microplastics transfer pollutants

The small size and large surface area of microplastics enhance these processes, allowing them to adsorb heavy metals, organic pollutants, pharmaceuticals, as well as bacteria and viruses. These can later leach from microplastics, posing threats to organisms and environmental health when the contaminated particles are ingested or otherwise enter food webs.

Particle size and shape greatly influence pollutant adsorption as smaller particles possess a higher surface-area-to-volume ratio, providing more active sites for pollutants to attach and increasing the overall sorption capacity. Irregularly shaped microplastics such as fragments and films have a varied surface structure and more accessible pores, resulting in greater pollutant adsorption compared to smoother, spherical particles. Additionally, weathered and eroded surfaces further enhance adsorption potential by increasing porosity and exposed active sites[13]. Studies have shown that microplastics with rough surfaces have a higher ecotoxicity potential[14]. In addition, adsorption increases the density and surface charge of particles, changing bioavailability and toxic effects. However, the shape effect can also vary with pollutant type and microplastic material, and aggregation of many particles may reduce the available surface for adsorption.

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[12] The microplastisphere is generated as larger plastics fragment, increasing total surface area in water and other environments.

[13] Rai et al (2021) Adsorption of environmental contaminants on micro- and nano-scale plastic polymers and the influence of weathering processes on their adsorptive attributes *Journal of Hazardous Material* 427 : 127903

[14] Rozman et al (2021) An extensive characterization of various environmentally relevant microplastics – material properties, leaching and ecotoxicity testing *Sci Total Environ* 773: 145576

Thus, smaller, porous, and irregular microplastics tend to accumulate more pollutants, amplifying their environmental toxic effects

Organic dyes and heavy metal ions, such as copper and cadmium, show strong shape-dependent adsorption onto microplastics, with films and irregular fragments exhibiting greater adsorption capacity compared to spheres. Studies of polyethylene microplastics found that dye molecules were adsorbed almost twice as much onto films as onto spheres or fragments, despite similar surface area[15]. Similarly, copper ions also adsorb significantly more onto film-shaped microplastics than other shapes. The particles' irregular geometry and increased accessibility of surfaces due to shape and porosity amplify their affinity for certain contaminants, making dyes, heavy metals, and some persistent organic pollutants especially shape-sensitive in their adsorption dynamics.

2.2 Marine and freshwater systems

In marine and freshwater systems microplastics are ingested by plankton, invertebrates, fish, and higher trophic organisms, disrupting feeding behaviour, energy transfer, and growth. Once ingested, microplastics can abrade gastrointestinal linings, cause energy depletion due to false satiation, and elicit immune and inflammatory responses. The surfaces adsorb hydrophobic pollutants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals. Adsorbed toxicants such as heavy metals and persistent organic pollutants (POPs) may desorb in gut conditions, releasing concentrated doses of hazardous substances and inducing oxidative stress, inflammation, and endocrine disruption. Microplastic accumulation in sediments and benthic communities also alters nutrient cycling, microbial composition, and the integrity of aquatic food webs. The persistence and bioavailability of microplastics in aquatic systems drive long-term bioaccumulation, with trophic transfer extending to human consumers.

2.3 Terrestrial ecosystems

In soils and agricultural landscapes, microplastics compromise key ecosystem processes. Their presence modifies soil porosity and water retention capacity, influences microbial metabolic activity, and interferes with root development and nutrient uptake, leading to observable declines in plant vigour and productivity. Plant ecotoxicological studies indicate that root uptake of nanoplastics can induce oxidative stress, impair chlorophyll synthesis, and stunt growth by disrupting water and nutrient flow. Through trophic transfer, invertebrates and soil-dwelling organisms accumulate both plastic particles and associated xenobiotics (chemical substances foreign to a biological system, including drugs, pesticides, food additives, and industrial pollutants), increasing the bioavailability of pollutants throughout the soil food web. Microplastics may act as vectors for agrochemicals, pathogens, and heavy metals, extending ecotoxicological interactions beyond simple physical contamination. Over time, their accumulation may reduce soil health, disrupt carbon cycling, and alter terrestrial food webs through plant-to-invertebrate transfer.

2.4 Atmospheric and cross-compartmental pathways

Atmospheric transport facilitates the redistribution of microplastics among ecological compartments. Airborne fibres and fragments deposit on terrestrial and aquatic surfaces, completing a global cycle of contamination. Inhaled microplastics represent emerging ecotoxicological and human health concerns, with evidence indicating respiratory tissue irritation and potential systemic distribution following chronic exposure. The atmosphere thus serves both as a transport medium and as a direct exposure route, heightening the complexity of ecological risk assessment.

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[15] Rozman et al (2023) Insights into the shape-dependent effects of polyethylene microplastics on interactions with organisms, environmental aging, and adsorption properties *Nature Scientific Reports* 13: 22147

2.5 Integrative ecotoxicological implications

Across all compartments, microplastics function as both physical and chemical stressors. They contribute to combined toxicity through leachates, sorbed contaminants, and biological uptake. Ingestion and contact with microplastics can cause physical damage, while the particles also act as carriers of additives and co-occurring pollutants, which may enhance toxicity through combined effects, [16,17]. Faster-degrading materials can reduce the duration of direct exposure but simultaneously increase the bioavailability of smaller fragments and degradation products, leading to complex trade-offs between reduced persistence and potential increases in short-term toxicity.

3 The case for biodegradable microplastics

Biodegradable plastics can initially form microplastic particles as they break down, raising concerns about short-term localised ecotoxicological "hotspots". Biodegradation rates of all plastics will vary with environmental conditions such as temperature, oxygen availability, moisture, light, pH, as well as microbial activity[11]. Unlike conventional plastics, biodegradable plastics are designed to mineralise completely, making microplastics a temporary intermediate rather than a permanent pollutant. Under optimised conditions, fully mineralised biodegradable plastics demonstrate minimal chronic toxicity and can integrate into natural biogeochemical cycles without contributing to pollutant buildup. A recent study examined long-term (>10 year) use of biodegradable mulch films under real field conditions and the effect on soil quality and microplastic accumulation: the findings showed neither noticeable microplastic buildup nor harmed soil function[18]. In environments like industrial composting systems, biodegradable fragments may initially behave similarly to conventional microplastics while present, potentially interacting with organisms or pollutants, but biodegradable microplastics ultimately break down and do not persist in the environment[1]. In aquatic environments, highly biodegradable microplastics have been shown to have a lower aquatic ecotoxicity than conventional plastics [19]. However, many of the same additive classes used in conventional plastics (such as plasticisers, stabilisers, antioxidants, flame retardants, colorants, fillers, as well as unreacted monomers and oligomers) are also used in biodegradable plastics and may leach during degradation and contribute to ecotoxic effects[20].

Research on the ecotoxicity of biodegradable microplastics is still developing, and the current evidence base remains relatively limited[21,22]. Early studies suggest that, like conventional microplastics, biodegradable particles can interact with environmental pollutants and may elicit biological responses in some experimental systems[23, 25]. These interactions are influenced by polymer characteristics such as crystallinity and surface area, which affect how particles adsorb contaminants and interact with organisms. In particular, adsorption behaviour varies depending on the specific polymer type being examined[24].

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[16] Weis & Alava (2023) (Micro) plastics are toxic pollutants *Toxics* 11(11) 935

[17] Yu et al (2024) Various additive release from microplastics and their toxicity in aquatic environments Environmental Pollution 34: 123219

[18] Mazzon et al (2026) Long-term biodegradable mulch films application in agricultural fields: effects on soil functionality and microplastic generation *Journal of Environmental Management* 398: 128594

[19] Piao et al (2024) Environmental impacts of biodegradable microplastics *Nature Chemical Engineering* 1: 661-669

[20] Courtene-Jones et al (2023) A review of biodegradable plastics from multidisciplinary perspectives

[21] Costigan et al (2022) Adsorption of organic pollutants by microplastics: overview of a dissonant literature *Journal of Hazardous materials Advances* 6: 100091

[22] Sforzini et al (2016) Application of Biotests for the Determination of Soil Ecotoxicity after Exposure to Biodegradable Plastics *Frontiers in Environmental Science* 4

[23] Mut et al (2024) A review on fate and ecotoxicity of biodegradable microplastics in aquatic system: Are biodegradable plastics truly safe for the environment? *Environmental Pollution* 344: 123399

[24] Saldi et al (2025) Role of biodegradable and non-biodegradable microplastics in modulating the toxicological effects of organic pollutants in the soil organism *Folsomia candida* *Water, Air and Soil Pollution* 236 (710)

Because biodegradable plastics can fragment into microplastics during the early stages of degradation, there may initially be an increase in particle surface area, which can influence their environmental interactions. Importantly, however, biodegradable microplastics represent a transitional phase in the degradation process. Unlike conventional plastics, they are designed to continue breaking down over time and ultimately mineralise into simpler compounds, enabling their removal from the ecosystem. As a result, biodegradable plastics offer the potential for reduced long-term persistence compared with traditional plastic materials.

Assessing overall environmental impact is complicated by inconsistent research methods and limited standardisation in microplastics studies, as well as physico-chemical definitions used (including particle size, surface area, porosity, water type and salting out, and adsorption parameters)[Error! Bookmark not defined.]. Regulations, however, offer reassurance: biodegradable plastics that have been certified according to international standards will have passed strict ecotoxicological tests. Indeed, comparative evaluation of a comprehensive suite of standardised chronic and acute ecotoxicological assays encompassing diverse model organisms (including bacteria, protozoa, algae, plants, crustaceans, and earthworms) demonstrated that the certified biodegradable material produced no adverse effects[25]. These tests show that, when properly degraded under specified conditions, such materials exhibit minimal chronic toxicity and can integrate safely into natural biogeochemical cycles.

4 Key regulations and standards

Ecotoxicological testing of microplastics is governed by a mix of chemical safety, environmental, and product-specific frameworks. The main EU regulatory instrument that protects human and environmental health from chemicals is EU Regulation No 1907/2006, the Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)[26]. Commission Regulation (EU) 2023/2055 establishes restrictions on intentionally added microplastics under the REACH[27].

4.1 Regulation (EU) 2023/2055 (REACH Amendment)

This came into effect in October 2023 and restricts the use of synthetic polymer microparticles (microplastics) intentionally added to products. To be exempt, biodegradable polymers must demonstrate compliance with biodegradation criteria using defined standard tests. Acceptable test methods include OECD 301B, 301D, and 301F for ready biodegradability in aerobic aqueous environments, with a pass threshold of 60% degradation within 28 days[28]. Exemptions are considered for polymers that are water-soluble or naturally occurring without chemical modification[29]. The restriction of microplastics in a way similar to EU 2023/2055 has not yet been fully transposed into UK REACH.

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[25] Sforzini et al (2016) Application of Biotests for the Determination of Soil Ecotoxicity after Exposure to Biodegradable Plastics *Frontiers in Environmental Science* 4

[26] The UK largely mirrors EU REACH rules but administers them under UK REACH.

[27] BB-REG-NET (2025) Plastic Definitions in UK regulation

[28] Commission Regulation (EU) 2023/2055 amending Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as regards synthetic polymer microparticles

[29] A comprehensive discussion of this term is presented in BB-REG-NET (2025) Plastic definitions in UK regulation

4.2 Standards for biodegradable polymers

Products that claim biodegradability or compostability within the EU are tested under specific EN standards:

- **EN 13432:2000** Industrial composting standards for packaging; includes heavy metal limits and ecotoxicity testing via plant growth tests.
- **EN 17033**:**2018** Biodegradable mulch films for soil applications; includes ecotoxicity, nitrification inhibition, and earthworm tests.
- **EN 14995:2006** Plastics evolution of compostability test scheme and specifications: includes plant growth tests.

Ecotoxicological testing in these standards ensures the resultant material or compost does not negatively affect microorganisms, plants, or soil fauna.

4.2.1 EN 14995:2006 (evaluation of compostability) EN 13432:2000 (industrial composting standards for packaging) and ISO 17088:2021 require plant growth inhibition tests to ensure resultant compost is not toxic to the environment.

EN 14995:2006, EN 13432:2000 their international counterpart ISO 17088:2021 and, in the USA, ASTM D6400 share similar ecotoxicity requirements but differ slightly in detail and allowable limits. EN 13432:2000 is typically more conservative in ecotoxicity limits than ASTM D6400, with ISO 17088:2021 incorporating the most recent test types. All standards mandate that compost produced after biodegradation must be safe for plant growth, requiring plant germination and biomass tests with a minimum >90% germination rate compared to controls.

- **EN 13432:2000 is a European standard that defines the criteria for packaging materials to be certified as industrially compostable.** This mandates that they biodegrade in commercial composting facility 90% of the fragments are smaller than 2 mm after 12 weeks and that at least 90% of the material is converted to carbon dioxide within 6 months under controlled composting conditions. EN 13432:2000 also mandates that the product passes specific ecotoxicological testing to demonstrate that the compost produced from the biodegradation process does not negatively affect plant growth or soil quality, using OECD 208 guidelines modified as per its annex to conduct plant growth tests. It also sets limits on heavy metals and other chemical contaminants in the compost.

- **EN 14995:2006 is another European standard that provides specifications for compostability and anaerobic treatability of plastic materials.** It applies similar criteria to all compostable plastics, not just packaging, and requires ecotoxicity and heavy metal testing of the final compost. The ecotoxicity testing is implemented through a plant growth test on two higher plant species (based on OECD 208). Microbial toxicity is covered through a nitrification inhibition check on soil microbial activity.

- **The more recent ISO 17088:2021 is an international standard providing a broad framework for compostability**. It includes similar core criteria on biodegradation, disintegration, and ecotoxicity. ISO 17088 also aligns with OECD 208 but adds a nitrification inhibition test mandating >80% inhibition of nitrite formation in compost, a newer criterion evolving beyond EN 13432:2000. The test evaluates whether the material (via its compost or residues) inhibits the nitrification process carried out by soil microorganisms, and the acceptance criterion is that nitrification in treated soil must reach at least 80% of the level measured in untreated control soil, indicating no significant toxic effect on the microbial community. Additionally, ISO 17088:2021 allows some flexibility in test extrapolation for varying thicknesses of material.

- **ASTM D6400 follows OECD 208 methods** with similar criteria but generally allows higher limits for hazardous substances such as heavy metals compared to EN 13432:2000, which has more stringent chemical limits overall.

ISO 17088:2021 functions as a global counterpart to EN 13432:2000 and EN 14995:2006, harmonising requirements for compostable plastics across different regions (see Appendix for comparison between EN and ISO systems). If a product meets EN 13432:2000 or EN 14995:2006, it generally satisfies ISO 17088:2021 as well, promoting international consistency for compostability claims.

4.2.2 EN 17033:2018 (biodegradable mulch films for soil applications) and ISO 23517:2021 (soil biodegradable materials for mulch films for use in agriculture and horticulture) mandate no negative ecotoxicological effects.

In addition to standards for compostability, EN 17033:2018 (biodegradable mulch films for soil applications) mandates no negative ecological effects on soil organisms, including earthworms, as well as plant ecotoxicity testing. EN 17033:2018 is a European standard specifically developed for biodegradable mulch films used in agriculture and horticulture. Films must 90% degrade to carbon dioxide within 24 months in soil at ambient temperature. The standard also requires comprehensive testing addressing acute toxicity to plants (≥90% germination and growth compared to control), earthworms (≤10% difference in mortality and biomass), and soil microorganisms through nitrification inhibition tests (≥80% activity relative to control). It also restricts levels of heavy metals and substances of very high concern to safeguard soil health.

ISO 23517:2021 (plastics — soil biodegradable materials for mulch films for use in agriculture and horticulture) is a comparative global standard focussed on biodegradable mulch films but can also be used for other soil-biodegradable plastic products such as drip tape, twine, clips, and plant pots. It is more prescriptive and considers multiple exposure pathways, linking soil to aspects of nutrient recycling as well as more detail on test criteria beyond EN 17033:2018 baseline.

4.3 The EU Fertiliser Regulation

The EU Fertilising Products Regulation (EU 2019/1009) (FPR) is a comprehensive and harmonised framework governing the quality, safety, and labelling of fertilising products marketed across the European Union. It covers a broad array of product categories including inorganic, organic, organo-mineral fertilisers, liming materials, soil improvers, growing media, inhibitors, plant biostimulants, and blends. The regulation aims to ensure that fertilisers contribute to nutrient efficiency and safe soil management while promoting the use of secondary raw materials, bio-waste, and by-products. It mandates strict maximum limits on contaminants such as heavy metals, with provisions allowing member states to impose even lower thresholds to protect soil health and human safety.

From 2024, the FPR now explicitly includes biodegradable and biobased agricultural mulch films, classifying them as soil improvers and recognising agronomic benefits through improving soil temperature and moisture, controlling weeds and reducing pesticide use, and ultimately enhancing crop yield and quality. Biodegradable mulch films are designed to degrade fully in soil, addressing plastic pollution and the accumulation of microplastics from conventional plastic mulch films that are often difficult to retrieve after use[1].

The regulation requires that fertilising products meet rigorous safety criteria, including assessments of harmful substances, microbial safety, and potential ecological impacts. While explicit ecotoxicity tests like those in compostability standards are not detailed, requirements on contaminant limits, particularly for heavy metals and persistent pollutants, are a preventive measure against toxic accumulation in soil ecosystems.

Whilst the FPR does not prescribe a standardised set of specific ecotoxicological tests for all fertilisers, it does detail testing requirements dependent on the product category and the substances involved. Biodegradable and biobased agricultural mulch films are included under Component Material Category 9 'Other Polymers', classifying them as soil improvers within Product Function Category 3. Ecotoxicological assessments include plant growth acute toxicity tests, earthworm acute toxicity tests, and nitrification inhibition tests in soil.

The regulation requires that polymers used in mulch films comply with specific biodegradability criteria both in soil and aquatic environments, ensuring at least 90% degradation or mineralisation within 48 months or an accelerated equivalent test. Ecotoxicological assessments include plant growth acute toxicity tests, earthworm acute and chronic toxicity tests, and nitrification inhibition tests in soil to confirm that the polymer and its degradation by-products do not adversely affect animal or plant health or the environment under foreseeable use conditions.

Standards such as EN 17033:2018 and ISO 23517 support certification and testing protocols to verify biodegradability and ecotoxicological safety. Certified soil-biodegradable mulch films bearing the CE mark can now be marketed across the EU, evidencing compliance with these standards.

4.4 Analytical and monitoring standards

Certification of biodegradable microplastics requires verification of both biodegradation performance and ecotoxicological safety in accordance with standardised OECD and EN compostability standards (Table 1).

EU microplastic assessment testing often uses ISO 24187 and ISO 16094 for particle identification and quantification through µFTIR, µRaman, or pyrolysis-GC/MS methods. These are applied especially where compliance with the REACH microplastics restriction must be demonstrated analytically.

Category	Relevant regulation/standard	Ecotoxicological aspects
Microplastics restriction	REACH Reg. (EU) 2023/2055	Biodegradability testing (OECD 301B/F/D)
Industrial compostable plastics	EN 13432:2000	Toxicity to plants (OECD 208)
Soil biodegradable plastics	EN 17033:2018	Soil organism and nitrification effects
Analytical confirmation	ISO 24187 / ISO 16094	Particle characterisation
Laboratory quality	Directive 2004/10/EC (GLP)	Method validation and traceability

Table 1 Summary of test and ecotoxicity framework

The primary OECD test explicitly named is OECD 208 (plants), with earthworm toxicity referenced via ISO standards equivalent or related to OECD 207, supplemented by microbial activity tests consistent with ecotoxicological evaluation frameworks. For example, the OECD ecotoxicity test methods referenced in EN 17033:2018 for biodegradable mulch films include:

EN 17033:2018 applies these tests across different exposure pathways (such as soil solid material, soil pore water, and soil pore air) to evaluate the ecotoxic effects on terrestrial organisms crucial for soil health. The specific clauses in EN 17033:2018 that list the OECD test references are found in:

- Clause 2 Normative References which includes key test standards and guidelines.
- Clause 5.3 Ecotoxicity details requirements for ecotoxicity testing. It specifically references the following OECD test guidelines for ecotoxicity assessments:
    - OECD 208: Terrestrial Plant Test (seedling emergence and seedling growth) used to assess acute ecotoxicity to plants. It measures germination rate and plant growth in soil containing the test material compared to control soil.
    - Ecotoxicity testing for earthworms as acute toxicity tests: referencing ISO 11268-1 and ISO 11268-2, which correspond to OECD 207 for earthworm toxicity: acute toxicity testing on earthworms (e.g. *Eisenia fetida* or *E. andrei*) focusing on mortality and biomass changes after exposure to soil with the biodegradable polymer.
    - Nitrification Inhibition Test: although there is no direct OECD test reference, it involves measuring nitrification inhibition in soil microorganisms, with the standard requiring nitrification to be at least 80% of that in untreated control soil.

4 Conclusions

Plastic pollution — particularly in the form of persistent microplastics — represents a systemic and long-term environmental challenge across aquatic, terrestrial and atmospheric compartments. The evidence reviewed in this report confirms that microplastics can act simultaneously as physical stressors, sources of chemical release, and vectors for other hazardous substances. These characteristics underpin wide-ranging ecotoxicological effects, including impacts on organism health, ecosystem processes, and trophic transfer. Persistence is a defining driver of risk: the longer particles remain in the environment, the greater the potential for accumulation, transport, and biological interaction.

Within this context, biodegradable plastics present a materially different environmental profile from conventional plastics. While biodegradable materials may generate microplastic fragments during the degradation process, these fragments represent a transitional phase within a continuum of breakdown that ultimately leads to mineralisation into biomass, carbon dioxide and water under suitable conditions. This fundamental distinction — transient versus persistent microplastics — is central to understanding their comparative environmental significance.

Evidence indicates that biodegradable microplastics can, during their presence, interact with organisms and co-occurring pollutants in ways that may resemble conventional microplastics. Under certain environmental conditions, particularly where biodegradation is slowed or incomplete (such as low oxygen, cold, or nutrient-poor environments), short-lived localised ecotoxicological effects may occur. Polymer characteristics, additives, environmental conditions, and interactions with other contaminants can all influence outcomes. Therefore, biodegradable microplastics may temporarily increase microplastic abundance before breaking down further but ultimately do not contribute to permanent accumulation in ecosystems. Where mineralisation proceeds effectively, biodegradable plastics integrate into natural biogeochemical cycles without contributing to long-term pollutant build-up.

The balance of evidence therefore indicates that biodegradable plastics shift environmental risk from persistent accumulation toward temporary exposure. This represents a fundamentally different risk profile rather than the elimination of all potential effects. Managing this trade-off requires attention to environmental conditions, product design, additive composition, and appropriate end-of-life pathways.

A key finding of this report is that regulatory and certification frameworks play a decisive role in ensuring environmental safety. Established standards for compostable and soil-biodegradable plastics incorporate ecotoxicological endpoints directly into certification criteria. These frameworks require demonstration not only of physical disintegration and biodegradation, but also of biological safety following degradation. Testing across representative organisms and environmental functions ensures that certified materials do not cause harmful effects in their intended receiving environments. As such, compliance with recognised standards provides an evidence-based assurance that certified biodegradable plastics meet defined ecological safety thresholds.

At the same time, the report highlights important scientific and methodological challenges that affect the broader assessment of microplastics. Inconsistent experimental design, limited environmental realism in laboratory studies, and incomplete characterisation of particle properties continue to constrain comparability across studies. Data specific to biodegradable microplastics remain limited, particularly regarding long-term exposure dynamics, transformation products, and interactions with complex contaminant mixtures. These knowledge gaps do not negate existing evidence of environmental compatibility under certified conditions, but they do indicate areas where further research is warranted.

Overall, the findings support several overarching conclusions:

1. **Microplastic persistence is a primary determinant of long-term ecotoxicological risk**, and biodegradable plastics materially reduce this persistence relative to conventional polymers.
2. **Biodegradable microplastics can produce temporary ecological interactions**, but these occur within a degradation pathway that ultimately removes material from the environment.
3. **Certified biodegradable plastics that meet established standards demonstrate environmental compatibility under defined end-of-life conditions**, providing a robust regulatory safeguard.
4. **Environmental outcomes depend strongly on real-world degradation conditions**, highlighting the importance of appropriate product use, waste management infrastructure, and material design.
5. **Further research and methodological harmonisation are needed** to refine risk assessment, particularly for transient degradation phases and multi-stressor interactions.

In conclusion, whilst biodegradable plastics will form microplastics as part of their degradation, they will eventually mineralise to carbon dioxide and biomass. When properly designed, certified, and managed, biodegradable microplastics represent a credible and evidence-based strategy for reducing the long-term ecological burden associated with persistent plastic pollution. They do not eliminate all environmental interactions during degradation, but they substantially alter the trajectory of plastic residues by preventing indefinite accumulation. Continued advancement in material design, environmental monitoring, and regulatory alignment will be essential to maximise benefits while minimising transitional impacts.

Appendix 1: Comparative table of ISO versus EN standards

Aspect	ISO Standards	EN Standards
Scope	Global applicability; harmonizes requirements internationally	EU-specific; mandatory for CE marking
Purpose	Facilitates worldwide trade and interoperability	Ensures compliance with EU directives and environmental safety
Examples	ISO 17088:2021 – Compostable plastics standard	EN 13432:2000 – Industrial composting for packaging
Flexibility	Includes newer scientific updates; nitrification inhibition tests	More prescriptive; stricter chemical limits
Regulatory Link	Voluntary unless adopted nationally; widely used for certification	Directly tied to EU laws and CE marking
Alignment	Increasing harmonisation; ISO covers broader product categories	EN standards are often more conservative on chemical limits

Appendix 2: Acronyms and standards

This appendix provides a consolidated reference of acronyms and test standards mentioned in the report, their full names and descriptions, and details why these standards matter for ecotoxicology compliance.

Acronym	Full Name	Description
BPA	Bisphenol A	Plastic additive; leaches from microplastics.
PCBs	Polychlorinated Biphenyls	Persistent pollutants adsorbed on microplastics.
PAHs	Polycyclic Aromatic Hydrocarbons	Hydrophobic pollutants adsorbed on microplastics.
POPs	Persistent Organic Pollutants	Hazardous chemicals transported by microplastics.
OECD	Organisation for Economic Co-operation and Development	Publishes biodegradability and ecotoxicity test guidelines.
ISO	International Organisation for Standardisation	Global standards body (e.g. ISO 17088).
EN	European Norm	European standards (e.g. EN 13432).
ASTM	American Society for Testing and Materials	US standards body (e.g. ASTM D6400).
FPR	Fertilising Products Regulation	EU regulation for soil improvers.
CMC	Component Material Category	Classification under EU Fertiliser Regulation.
CE	Conformité Européenne	Marking for EU compliance.

Standard/Test	Full Name	Key Requirements
EN 13432:2000	Packaging – Compostability Standard	≥90% CO_2 in 6 months; disintegration; ecotoxicity (OECD 208); heavy metal limits.
EN 17033:2018	Biodegradable Mulch Films	Soil biodegradation; plant, earthworm, microbial toxicity tests.
ISO 17088:2021	Compostable Plastics	Global compostability; nitrification inhibition test.
ASTM D6400	Compostable Plastics Standard	Similar to EN 13432:2000; higher chemical limits.
OECD 301B/D/F	Ready Biodegradability Tests	≥60% degradation in 28 days.
OECD 208	Seedling Emergence and Growth	Plant ecotoxicity assessment.
OECD 207	Earthworm Acute Toxicity	Mortality and biomass change.
ISO 24187 / ISO 16094	Microplastics Identification	µFTIR, µRaman, pyrolysis-GC/MS methods.
Directive 2004/10/EC	Good Laboratory Practice	Quality and traceability for testing.

These standards ensure biodegradable plastics are assessed for both breakdown performance and ecological safety:

- EN and ISO compostability standards require proof that compost or soil does not harm plants, soil fauna, or microbial processes
- OECD tests quantify biodegradation rates and ecotoxicological endpoints.
- Analytical ISO methods confirm microplastic identity and concentration to support regulatory compliance (EU REACH and UK REACH)
- GLP ensures tests are reliable and traceable.

Together, they provide an evidence base linking material claims to real-world environmental protection.