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MINAGRIS - MIcro- and NAno-Plastics in Agricultural Soils: sources, environmental fate and impacts on ecosystem services and overall sustainability – is an H2020 project funded under the H2020 Programme, coordinated by WAGENINGEN UNIVERSITY (WU).

The MINAGRIS project, launched on September 1st, 2021, aims to contribute to healthy soils in Europe by providing a deeper understanding and tools to assess the impact of micro- (MP) and nano- (NP) in agricultural soil health. To create an overview on the actual situation across Europe, MINAGRIS will assess the use of different plastic polymers in agricultural systems in 11 case study sites across Europe and identify the resulting types and concentrations of MPs and NPs. Concentrations of other stressors in soils such as pesticides and veterinary drugs will be additionally assessed but are not part of this report. MINAGRIS will provide validated analytical tools that allow the quantification and identification of MPs and NPs in European agricultural soils.

The project, funded by the EU Research and Innovation Programme Horizon 2020 under Grant Agreement n. 101000407, gathers 20 partnering organisations from 12 EU Member States countries with various biogeographical regions and representative of different farming systems and soils across Europe. It has an overall budget of approximately €7 million and will run for 5 years, between September 2021 and September 2026.

More information on the project can be found at: https://www.minagris.eu

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LIST OF ABBREVIATIONS

AP: Agri-plastics

BAT: Best Alternative Techniques

BREF: Best Available Techniques Reference Document

CSS: Case Study Sites

EoL: end-of-life

EPR: Extended Producer Responsability

FPR: Fertilizing Product Regulation (UE) 1009/2019

MaP: macroplastics

MeP: mesoplastics

MiP: microplastics

MNP: micro and nano plastics NP: nano plastics

EXECUTIVE SUMMARY

The BREF (Best available techniques REFerence) document aims to provide evidence-based, scientific and technical support for decision-making processes concerning the sustainable use of plastics in agriculture, with a specific focus on the prevention and reduction of micro- and nanoplastic (MNP) emissions to soils and connected ecosystems. BREF is based on scientific literature dealing with use of plastics in agriculture, MINAGRIS project results on effects of MP on soil organisms and plants, results from the stakeholder forum surveys carried out in the case study sites (CSS), results obtained from the main European agri-plastics stakeholders' and finally integrates the main variables, and scenarios used in the Decision Support Tool elaborated in MINAGRIS project.

The document should identify, evaluate and recommend Best Available Techniques (BATs), management practices, biodegradable alternatives and monitoring approaches applicable across the agricultural plastic value chain, with the aim to support technical advisers, growers, industry, while underlying the need in terms of legislative framework homogenization and policy implementation, and suggesting sustainable agricultural practices.

The proposed BATs will take into considerations different aspect of the agri-plastics value chain putting together all the elements emerged during MINAGRIS project with the aim of reducing environmental pollution. The BATs proposed range from general management approaches for the agri-plastics end-of-life (EoL) to suggesting alternative good practices and materials.

1. INTRODUCTION AND SCOPE

1.1. Introduction

The use of plastics in agriculture has increased dramatically over the past decades. Plastic materials provide important agronomic benefits, including improved water management, weed suppression, enhanced crop yields and reduced food losses. Agricultural applications include mulch films, greenhouse films, irrigation systems, bale wraps, twines and clips, controlled-release fertilizer coatings, seed coatings.

However, the degradation and fragmentation of these materials may lead to the release of macroplastics (MaP), microplastics (MiPs, <5 mm) and nanoplastics (NPs), contributing to long-term soil contamination. Agricultural soil is now considered important environmental reservoirs for MNP accumulation. Unlike aquatic systems, where plastics may be transported away, soils tend to retain particles for long periods, potentially leading to cumulative contamination over decades.

The European Union increasingly recognizes microplastic pollution as a priority environmental issue. Recent developments include:

- REACH restriction on intentionally added microplastics,
- Soil Monitoring Directive,
- Fertilizing Products Regulation (FPR),
- Delegated Regulations on biodegradable polymers for mulch films and fertilizer coatings.

MINAGRIS project represents together with the twin project PAPILLONS the first European project systematically studying the effects of microplastics (MiP) in soils and their interactions with some additives, while analyzing the presence in real field conditions.

1.2. Scope of BREF

This Best Available Techniques Reference Document (BREF) defines a comprehensive framework addressing the sustainable use of plastics in agriculture (both for vegetable and animal use) across the European value chain, with a particular focus on the prevention and reduction of micro- and nano-plastic (MNP) emissions to agricultural soils. The scope covers the full life cycle of agricultural plastics, including material design and production, use in agricultural systems, collection, waste management, and end-of-life pathways, reflecting evidence that plastic losses and microplastics can occur at all stages and accumulate particularly in soils. The BREF is specifically oriented toward plastic applications for agriculture deliberately or/and not deliberately introduced into agricultural environments (e.g. mulch films, irrigation components), while considering their degradation into microplastics and their environmental fate (European Commission. Joint Research Centre., 2025; (European Commission. Directorate General for Environment, 2023, EUNOMIA, 2021).

The primary objective of BREF is to provide scientifically robust, evidence-based and actionable guidance on Best Available Techniques (BATs) that minimize plastic leakage, optimize material use, and improve circularity in agricultural systems. It aims to support environmentally sound decision-making by identifying key emission sources, technical and non-technical barriers (such as low collection rates, contamination, and limited recycling markets), and effective mitigation measures along the value chain. In doing so, it contributes to broader EU policy targets, including reducing microplastic releases

and promoting a circular economy for plastics (EUNOMIA, 2021) (European Commission. Joint Research Centre., 2025).

The system boundaries of the BREF are aligned with a life-cycle perspective, encompassing production, consumption, waste generation, and environmental leakage, while explicitly recognizing key data gaps, monitoring limitations, and uncertainties, particularly regarding soil contamination, biodegradation processes, and long-term impacts. These boundaries also integrate material flow and environmental impact considerations, enabling the identification of hotspots and priority intervention areas across sectors and processes. (EUNOMIA, 2021; European Commission, Directorate General for Environment., 2023; European Commission. Joint Research Centre, 2025)

The intended use of BREF is to serve as a reference and guidance tool for growers, industry operators, technical advisors, policymakers, and Standardisation bodies. It is designed to support Technical Working Groups and Standardization Working Groups in developing technical conclusions, standards, and regulatory measures, while also enabling practitioners to implement practical solutions that reduce emissions, enhance resource efficiency, and support the transition toward a sustainable and circular bioeconomy.

2. USE AND END-OF-LIFE OF AGRICULTURAL PLASTICS

2.1. Plasticulture

The term "*plasticulture*" (made by joining "*plastic*" and "*agriculture*") was first used in the 50ies and demonstrate the importance that plastic materials had reached in agriculture practices and recognizing the key role of innovation and high level of technology and integration of a wide range of plastic products in the agronomical techniques.

Plastic materials have dramatically changed and improved agricultural practices, marking a shift in agricultural techniques, introducing innovative ways to enhance crop production, optimize resource usage, reduce the food loss and waste, increase the use of land in arid areas, maintain the quality of food and feed and enhancing the shelf life, reduce the use of inputs (fertilizers and phytosanitary products) and improve the overall efficiency in the agricultural sector. Thanks to their versality and broad range of possible conversion technologies, can be transformed into a wide range of products: films, nets, threads, clips, tubes, pipes, with many purposes and specific applications, as reported in Table 1.

Product category	Intended purpose	Specific application	Mainly used polymer
Covers and films	Crop protection (not in direct contact with soil)	• Greenhouse and large tunnels • Low tunnels • Nursery films • Direct covers • Covers for vineyards, orchards	LDPE, EVA
	Soil conditioning (in direct contact with soil	• Mulching films • Direct covers	LDPE
	Protection and storage of animal feed (e.g. forage, silage, hay, maize)	• Silage films • Bale wraps • Silage bags • Stretch films	LDPE
Netting and twine	Crop protection Collection and storage of crops	• Bale twines • Non-woven nets (e.g. olive and nuts collection) • Bale nets • Protective nets (windbreaks,/anti-hail/anti-bird/shading	PP, HDPE, LDPE
Irrigation systems	Water management	• Irrigation pipes and drippers • Drainage tapers and channel linings	LDPE, HDPE, PVC, PRFV
Receptacles, bags and containers	Harvesting, packaging, tranportation and storage of crops and plant protection products	• Pesticide containers • Fertilizer sacks • Liquid tanks • Storage crates	LDPE, PP, PS, HDPE, PVC, PRFV, PMMA

Table 1.Various uses of plastics in agriculture (Scarascia-Mugnozza et al., 2011).

According to a recent FAO Report 13.4 million tons of plastic products were used in the agricultural sector for plant and animal production , with a forecast of increasing demand for greenhouse, mulch and silage (FAO, 2026). Still the percentage of plastic materials in agriculture remains quite small compared to other applications: around 5% of the total amount (European Investment Bank and European Commission, 2023).

Film applications account for 75% of all the plastics used for crops and animal production. Asia is the largest user of plastics in agriculture, accounting for up to 6 million tons annually (about 70% of the global use of films, (Castellon Petrovich, H.F., 2019; Jansen et al., 2019; Plastics Europe, 2019). In Europe it has been estimated that 722 k ton of plastics per year are used for a wide range of agricultural

applications such as films (greenhouse, low-tunnel, mulches, silage), to nets (birds, insects, and hay protection, for growing vegetables, for preserving hay and forage), tubes and pipes for irrigation, strings and twines, containers, dispensers, coating agents, clips (FAO, 2021). (Figure 1)

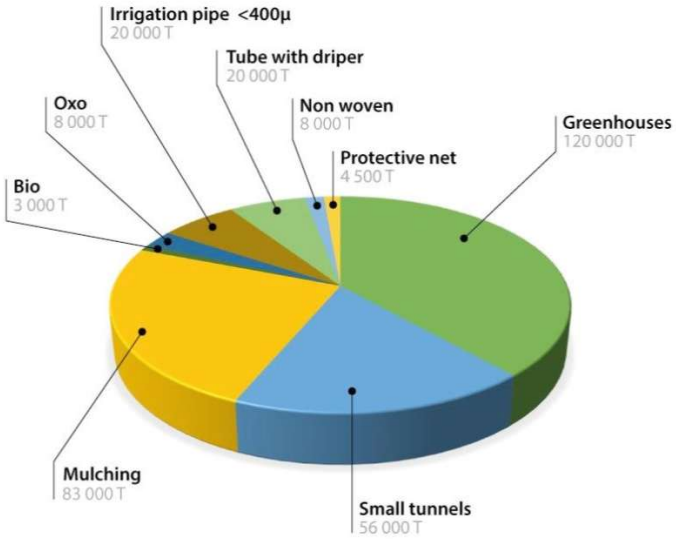

Figure 1. Plasticulture for vegetable production in Europe, 2019 (APE Europe, 2019).

The European countries where plastic films are mostly used are Spain (93 ktons) and Italy (89 ktons), followed by France and Germany (respectively 70 ktons and 57,5 ktons, APE Europe, 2019).

According to a forecast by Le Moine (APE Europe, 2019), Asia is the area where plastic films will grow most and more significantly in the next 15 years, while Europe and North America will have a less important trend as shown in Figure 2.

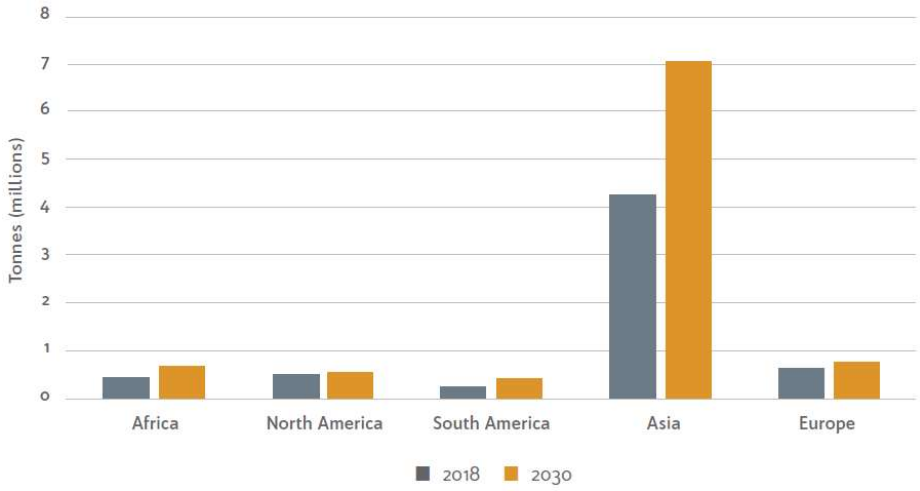

Figure 2. Use of plastic films in agriculture in different regions (APE Europe, 2019).

The main plastic material used for agricultural applications can be referred to as polyethylene (PE), in low density (LDPE) and low linear (LLDPE) versions. Other commonly used polymers used in agriculture are polypropylene (PP), expanded polystyrene (EPS), ethyl-vinyl-acetate copolymer (EVA), poly vinyl chloride (PVC), and polyethylene terephthalate (PET). According to the features required for the final

products and the conversion technology, a broad range of additives and stabilizers are available and can be added (such as stabilizers, fillers, plasticizers).

In Europe it has been estimated that only 0.7 Mt of the total production of plastics could be attributed to bio-based polymers despite a growing trend in the share of bio-based plastic in the EU in recent years (European Commission, Joint Research Centre, 2025). The main applications of bio-based and biodegradable plastics are in packaging. In minor quantities biodegradable and compostable materials have started to be used for agricultural applications, even if they still represent a small percentage in comparison with conventional plastics. Despite the growing interest and use of these materials (as from European Bioplastics statistics – EUBP 2025) (EUBIO, n.d.). There is a lack of specific statistics on this application, but it has been estimated that the quantity of biodegradable and bio-base plastics used in agriculture amounts around 1% of the total plastics used in the sector (EUNOMIA, 2021).

2.2. End-of-life of agricultural plastics

At the end of their use in the field, agricultural plastics (AP) are considered an industrial waste, from non-hazardous economic activities. Therefore, in the absence of specific legislation agricultural plastic waste falls under the general legislation. Several European countries have their own regulations for collecting agricultural plastics but, apart from packaging plastics, there is no common European regulation for this type of waste. Agricultural plastics are specifically mentioned in the EU Commission waste list (200/532/EC, cat: 02 01 04, European Commission, 2000).

When on farm, plastic waste is under the responsibility of the farmer, who is therefore accountable for their elimination according to the concept "*the polluter pays*". This implies that plastic waste must be properly managed in order to avoid pollution: burying or burning are not allowed practices (EIP-AGRI, 2021). The farmers are not the only actors involved in agricultural plastic waste management, but this is a collective responsibility shared by all the actors involved in the value chain of production and use (producers, distributors). The Extended Producer Responsibility (EPR) is a principle laid down. Originally initiated by OECD, in the early 1980s, the ERP principle has been adopted by the European Union which has included more product categories to stop the increase of non-recyclable or non-biodegradable waste. Given its central importance, the EPR has been clearly mentioned in the Directive 2008 (European Commission, DG Environment, 2014) .

The situation concerning the end of life of AP in Europe is still not completely clear in terms of numbers and statistics: the figures are very different for different Member States. It is estimated that an average of 64% of AP nonpackaging waste was collected in 2019 (EUNOMIA, 2021). The collection is dependent on the type of plastic use and practices (National collection schemes) in the region. According to Eunomia only 24% of the collected AP is then recycled and again this percentage may vary in different countries (Deliverable D3.3, EUNOMIA, 2021); more recent data, obtained from analysing the end -of-life of plastic materials in Europe show that almost 39% of the total plastics used in agriculture are incinerated, and almost one third are still landfilled, while only over 28% are recycled (European Commission. Joint Research Centre., 2025) (Figure 3).

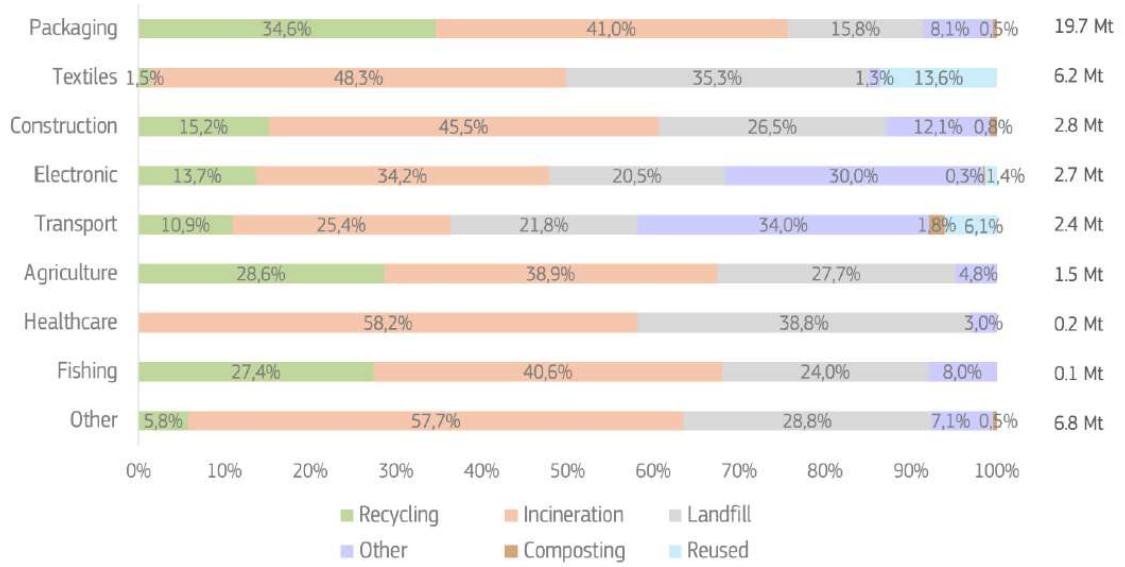

Figure 3. Rates (%) of total plastics sent to recycling, incineration, landfill, prepared to be reused or lost and mismanaged by each sector. The percentages are calculated based on the input amounts of the processes, and considering waste being generated and trade of waste. Possible rounding effects may be present in the data – JRC elaboration (European Commission. Joint Research Centre., 2025).

The uncollected or not properly disposed AP are the input sources for plastic accumulation in soil and MNP formation. Data per country on end-of-life for AP per country is missing and this makes the estimation of plastic quantities in the farm and possible sources of soil pollution difficult. According to a modelling conducted by Eunomia (Eunomia, 2021), looking at the likely scenario for the use of conventional mulch films, in Europe around 5-25% of mulch films are not properly removed at the end of their use, resulting in 4 750 -20 750 tons of conventional plastic remaining on agricultural soil every year (considering the annual use of 83 000 tons).

In its 2025, the study on “Plastic materials flows in the EU-27 and their environmental impact (done by the European Commission, Joint Research Centre, 2025) it is underlined, that the mismanagement of plastic waste pay a crucial role in the overall EU-27 plastic value chain, representing over 8 % of the potential fate of the total waste generated. In particular, 11.5% of the plastic waste dispersed in the environment is lost in soil (Table 2).

MFA steps	P	C	T	E	A	TEX	F	H	O	Total [kt]
Mac. to water	99.8	12.1	24.3	25.1	2.8	4.1	6.2	0.4	15.7	190.5
Mac. to soil	394.3	54.7	87.2	90.0	20.2	14.6	1.8	4.1	52.2	719.0
Mac. recollected	635.2	67.2	43.6	45.0	14.4	0.0	0.0	7.7	22.7	835.8
Mic. to water	138.4	33.0	91.2	18.5	13.1	58.9	0.6	2.2	168.1	523.9
Mic. to soil	651.5	45.2	341.2	20.1	15.2	67.0	0.7	2.3	128.3	1271.4
Mic. recollected	3.3	2.0	57.8	0.4	1.7	0.5	0.0	0.0	27.3	93.1

Source: JRC elaboration. Note: P = Packaging; C = Construction, T = Transport, E = Electronic, A = Agriculture, TEX = Textiles, H = Healthcare, F = Fishing, O = Other; Mic = microplastics; Mac = macroplastics.

Table 2. Sector-specific releases [ktonne] of plastics (sum of all releases along the value chain) per sector and per environmental compartment or potential recollection routes elaboration (European Commission. Joint Research Centre., 2025).

At present in Europe only Ireland and Sweden have established mandatory national collection schemes under the EPR, while France, Germany and Spain, Norway, and Iceland have implemented voluntary collection schemes and others (Greece, Belgium, and Poland) are about to start. In countries where National Collecting Schemes have been implemented the collecting rate of agri-plastic waste is between 75% and 95%, and the recycling rate can be up to 98% (EIP-AGRI, 2021).

2.3. Biodegradable and compostable materials for use in agriculture

2.3.1. Bioplastics: some definitions

"Bioplastics are not just one single material, but a broad family of materials with different properties *and applications. A plastic material is defined as a bioplastic if it is either biobased, biodegradable or features both properties*" (European Bioplastics, webpage (European Bioplastics, 2024). Early research and development on bioplastics were conducted during the 1980s and 1990s (Albertsson and Karlsson, 1996; Bastioli, 1998). Scientists and researchers explored the potential of using natural materials to create plastics as an alternative to traditional petrochemical-based plastics. The early 2000s saw the first commercial introduction of bioplastics. Bioplastics can be either biodegradable, bio-based or both (Figure. 4)

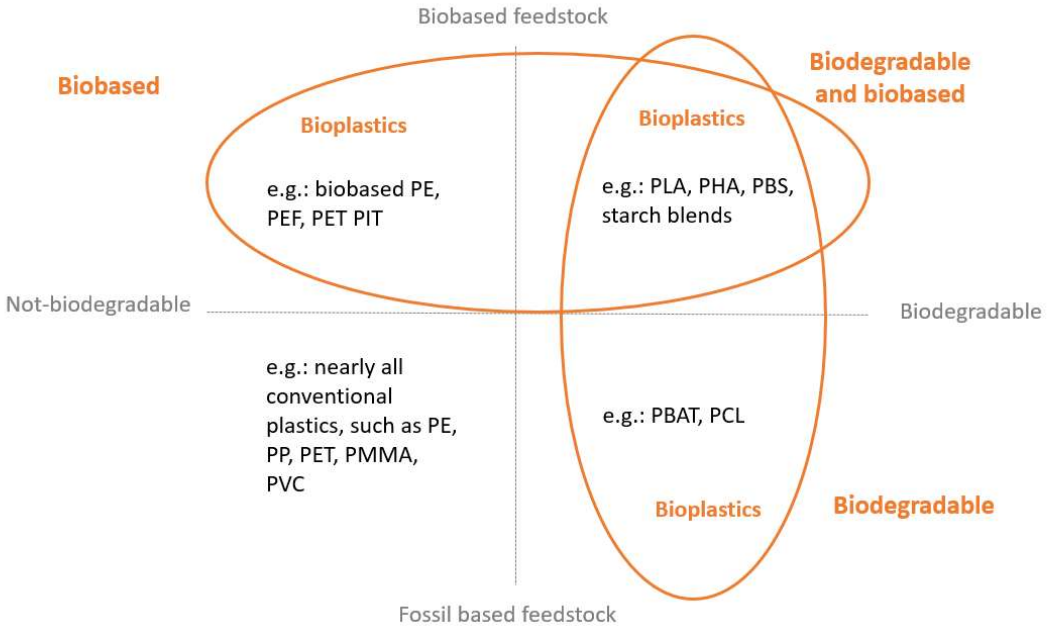

Figure 4. Classification of bioplastics based on their biodegradability and origin. Source European Bioplastics website, 2017.

According to IUPAC a **bio-based polymer** "*is composed or derived in whole or in part from biological products issued from the biomass (including plant, animal and marine or forestry materials)*" (Vert et al., 2012). These materials are composed of organic compounds and are part of the natural carbon cycle.

Biodegradability refers to a property of a substance, the ability typically of an organic material, to be broken down and decomposed into simpler compounds by the action of microorganisms, such as bacteria, fungi, or enzymes, over a specific period of time (Degli Innocenti and Breton, 2020). This natural process results in the conversion of the original substance into substances like water, carbon dioxide, and biomass.

Biodegradation refers to a process that can take place in some conditions and it is the measurable ability of microorganisms, present in the target environment, to use /assimilate the carbon substrate (RAPRA, 2014). In accordance with the target environment a biodegradable material can be

compostable (being degradable under industrial or home composting conditions), **biodegradable in soil or/and biodegradable in water**. Photodegradation and thermal degradation are terms referred to degradation processes occurring throughout the abrasion due to the actions of environmental factors such as light and heat and that can favor biodegradation. It is important to underline that biodegradability is a property linked to the chemical structure of a molecule therefore not dependent on the resource basis.

2.3.2. Biodegradation and standards

Biodegradation is a microbial driven process, and it is the natural end of life process that microorganisms in the environment use to assimilate and use carbon substrates as food for their life and reproduction. From a chemical perspective this means to convert organic molecules (such as proteins and sugars) into inorganic compounds (such as CO_2 and NH_3), and it is the reverse reaction to the photosynthesis performed by plants (from inorganic elements into organic molecules) (RAPRA, 2014). Applied to plastic materials (polymers) biodegradation is an option to reduce the presence of plastics (designed to be biodegraded) in specific environments (e.g.: water, compost, soil).

Standards have been developed over the last 20 years to quantify the biodegradability of plastics in the specific environments where the materials end their life. Namely, we can distinguish three main environments: compost, soil, and water (Briassoulis and Mistriotis, 2018).

Standards and norms are important instruments to ensure that the environmental claims on biodegradability and absence of ecotoxicity effects are scientifically correct, uniform, accurate and substantial. Standards have also the important function to facilitate the communication of environmental claims between industry, consumers, and authorities (De Wilde, 2021). It is crucial for producers and consumers to be aware of these norms and certifications to make informed decisions regarding biodegradable products and their environmental impact.

Standard tests assure not only the complete biodegradability of the test material in the end-of-life environment, but also the absence of negative effects, release of heavy metals or toxic substances and accumulation of persistent materials.

In 2018 the European Committee for standardization (CEN) released the first standard specifically designed for biodegradable mulch films: EN 17033:2018 "*Plastics - biodegradable mulch films for use in agriculture and horticulture – requirement and test methods*" (CEN, 2018). The standards specify the requirements for biodegradable mulch films intended to biodegrade in soil as summarized by Hayes and Flury, 2018 (Hayes and Flury, 2018) in terms of:

- Minimum biodegradation of 90% (absolute of relative to the reference materials) in soil according to the standard ISO 17556 "*Plastic determination of the ultimate aerobic biodegradability of plastic material in soil by measuring the oxygen demand in a respirometer on the amount of carbon dioxide evolved*", in a test period of 24 months, in natural soil at 20° to 28°C.
- Absence of toxic effect in soil: strict thresholds for heavy metals[1], ecotoxicity tests on target organisms (plant, earthworms, and bacteria) according to international norms (OECD 208 for plants, ISO 11268-1 and 23 for invertebrates – earthworms *Einsenia foetida*, and ISO 15685 for assessing ecotoxicity on microorganisms – nitrification inhibition of bacteria).

[1] Specifically: <150 mg/kg for Zn, <50 mg/kg for Cr, Cu, and Pb, <25 mg/kg for Ni, and <0.5 mg/kg for Cd and Hg.

- Control of constituent: hazardous substance of "very high concerns" (<0,1%) according to REACH are not allowed.
- Minimum requirements for mechanical and optical properties of mulch films[2].

In 2021 ISO released a standard setting the criteria for the definition of biodegradable mulch films: ISO 23517 "*Plastics – soil biodegradable materials for mulch films for use in agriculture and horticulture – requirements and test methods regarding biodegradation, ecotoxicity and control of constituents*". The standard is very similar in principles and structure to EN 17033. ISO 23517, while underlining the increasing importance and use of biodegradable mulch films worldwide, provides also the opportunity to certify biodegradable mulch films at global level, qualifying a common language for their definition (ISO, 2021).

The recent Commission Delegated Regulation (EU) 2024/2787 (*Commission Delegated Regulation (EU) 2024/2787 of 23 July 2024 amending Regulation (EU) 2019/1009 of the European Parliament and of the Council as regards the inclusion of mulch films in Component Material Category 9*, 2024), adopted under the Fertilizing Products Regulation (EU) 2019/1009, establishes harmonized requirements for biodegradable mulch films included in Component Material Category (CMC) 9, with a strong emphasis on both biodegradability performance and environmental safety. In particular, the Delegated Act requires that polymers used in mulch films achieve a high level of ultimate biodegradation in soil, typically at least 90% mineralization within a defined timeframe (generally 24 months plus the functional period), to prevent the accumulation of persistent plastic residues in agricultural soils. Furthermore, the regulation introduces a comprehensive ecotoxicological assessment scheme, including both acute and chronic toxicity endpoints, covering relevant soil organisms (e.g. plants, earthworms, and soil microorganisms) and ensuring that degradation products do not adversely affect soil functions or ecosystem health.

These requirements are broadly aligned with, and largely build upon, the existing European standard EN 17033:2018 for biodegradable mulch films. However, the Delegated Act under the Fertilizing Products Regulation introduces a more stringent and regulatory-driven framework compared to EN 17033, notably by embedding biodegradability thresholds and ecotoxicity criteria within a mandatory conformity assessment scheme linked to CE marking and market access across the EU. In addition, it explicitly addresses the prevention of polymer accumulation in soil as a policy objective and incorporates both acute and chronic ecotoxicity requirements, thereby strengthening the overall environmental protection dimension. In contrast, EN 17033 primarily functions as a voluntary harmonized standard specifying test methods, performance criteria, and product requirements, serving as a technical benchmark that is now effectively referenced and operationalized within the EU regulatory framework.

2.3.3. Biodegradable materials as a tool to reduce MiP accumulation in soil

When conventional non-biodegradable APs cannot be properly managed at EoL, biodegradable and compostable materials represent a practical solution, as represented in Figure 5.

[2] The tensile properties' requirements differ between 3 ranges of nominal thickness, <10 µm, between 10 and 15 µm, and >15 µm

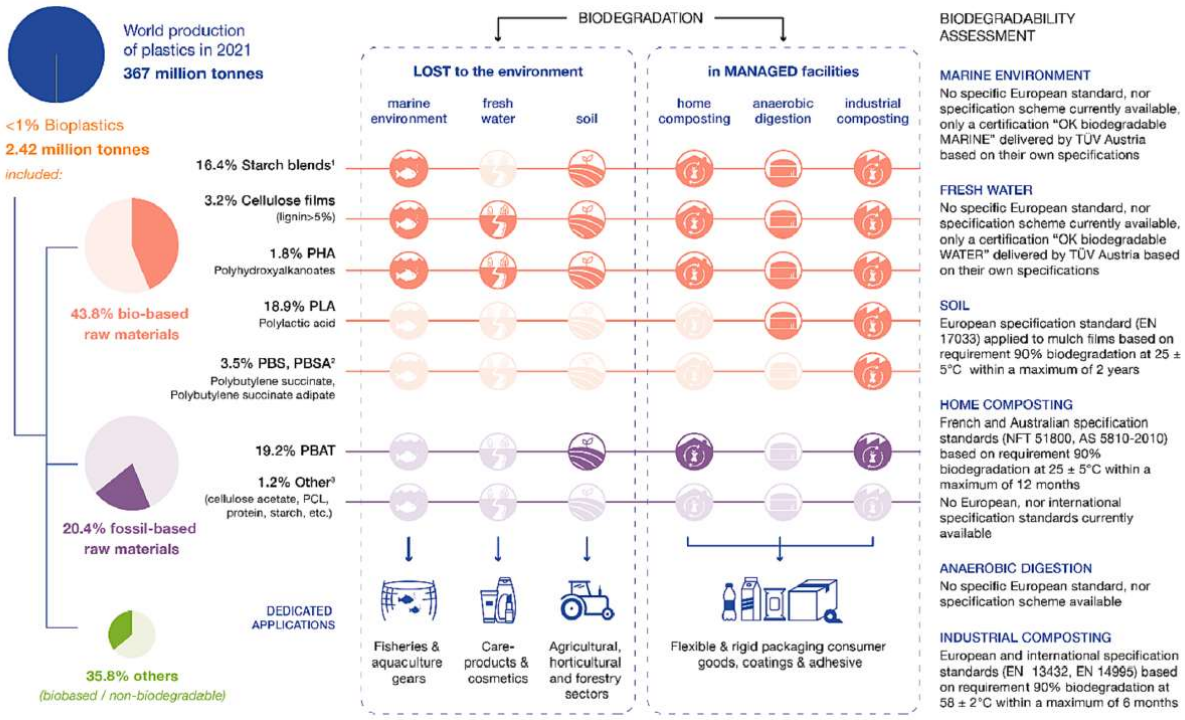

Figure 5. Distribution, biodegradability and suggested applications for biodegradable plastics.
Sources: European Bioplastics, nova-Institute (2021) wwww.european-bioplastics.org/market, www.bio-based.eu/markets, www.renewable-carbon.eu/graphics. Biodegradability assessment (right hand panel) refers to the existence of specification standards in a given environment. 1. Mater-Bi (Novamont Spa) of 3rd generation (MATER-BI AF03A0 AND MATER-BI AF05S0) are certified as biodegradable in aerobic marine conditions, https://ec.europa.eu/environment/ecoap/etv/aerobic-biodegradation-mater-bi-af03a0-and-mater-bi-af05s0-mater-bi-third-generation-under_en. 2. PBSA is biodegradable in soil and home composting conditions. 3. Other refers to different products displaying different ability to biodegrade according to a considered environment. Dedicated applications are suggested whenever complete removal of plastic material is not available. Colors represent bio-based-biodegradable (orange), petrol-based biodegradable (purple) and biobased non-biodegradable plastics (green). Small icons illustrate the end of life in the environment for biodegradable plastics, and the shading indicates absence of biodegradation in a given environment (Source: I. Paul-Pont et al., Waste Management 157 (2023) 242–248).

Biodegradable and compostable agri-plastics can play a significant role in enhancing the sustainability of agricultural systems by addressing key environmental and waste management challenges. In order to properly address environmental issues, it is important that the ecotoxicology aspects are taken into account. In particular, the adoption of biodegradable and compostable agri-plastics in compliance with the main international standards (such as EN 17033 and ISO 23517 for mulch films and EN 13432 for industrial compostable materials) or legislation (EU FPR 1009/2019) can contribute to:

- **Reducing the need for off-site management of agricultural plastic waste**, enabling *in situ* biodegradation or composting under controlled conditions. This can lead to lower logistical requirements, reduced transportation-related emissions, and decreased costs associated with collection, handling, and disposal of conventional plastic residues.
- **Minimizing the risk of mismanagement**, especially for applications characterized by a high probability of dispersion in the environment (e.g. mulch films, crop protection materials). Biodegradable alternatives can simplify EoL management pathways, reducing the dependency on complex recovery systems and mitigating the impacts of improper disposal practices.

- **Mitigating the release and accumulation of plastics and microplastics in agricultural soils** by securing 90% degradation in less than 2 year according to the standard, but according to MINAGRIS results, invertebrates might ingest, transport and being impacted by plastic residues even in the first 7 days that the plastic is integrated in the soil, therefore for securing soil quality, functionality, and long-term productivity. Therefore, it is of fundamental importance to comply with certification scheme requirements for soil biodegradability (in accordance with sectorial standards like EN 17033 or ISO 23517) or to comply with the criteria set for biodegradable mulch film in EU Fertilizing Product Regulation 1009/2019 in order to assess not only the biodegradability of the mulch film but also its ecotoxicology.
- The delegated act of FPR for biodegradable mulch films (Commission Delegated Regulation EU 2024/2787, 2024) considers several environmental aspects, to reduce risk and mitigate them such as:
    - "*Functionality period*" of a mulch film. It is defined as the period of time required for a much film to fulfil its functions (such as weed control, maintenance of water in soil, increase of soil temperature). The "functionality period" shall not be longer than the period between two application applications;
    - "*Buffer zone*": to create a "physical barrier" separating the area of use of a mulch film from the surface water bodies. "buffer zones" are those required for fertilising products in accordance with the relevant national rules or, in the absence of such rules, the product should be applied the product at least 3 m from any surface water body;
    - Defining good practices for managing the end of life of a biodegradable mulch film to reduce/avoid dispersion in the environment. Specifically, "an instruction to follow the national measures on handling mulch films after their functionality period or, in the absence of such measures, to incorporate in soil the product after its functionality period and maintain it buried".

3. STATE OF THE ART OF MICROPLASTICS IN EUROPEAN SOILS

In recent years several documents and literature became available, referring to the sustainability assessment of plastics for agriculture and their use and end of life (EIP-AGRI, 2021; EUNOMIA, 2021; FAO, 2021; UNEP, 2023). These references, together with the results from MINAGRIS project, represent the technical and scientific base on which the BREF has taken the data from its analysis.

MINAGRIS project (WP 2) performed the largest measuring campaign of macro-, meso-, micro- and nano-plastics done up to now and to our knowledge in agricultural soils in Europe. A total of 227 agricultural fields with a 20x20 m^2 area, belonging to 10 farms in 11 Case Study Sites across Europe, were systematically sampled and analyzed, representing different climatic conditions and different agronomic techniques (Deliverable 2.3). The Member states included in this campaign were: UK, France, the Netherlands, Estonia, Slovenia, Italy, Switzerland, Austria, Greece and Spain. The fields were selected to report an overview of the main crops/Member State and to take into consideration the different geo-pedological areas as well as including different agronomic techniques. The farmers were interviewed in their native language in three different surveys about their current practices in the last 5 and 10 years, as reported in Deliverable 3.3. Data from the surveys were analyzed and compared to the measured concentrations of macro and microplastics encountered in the fields.

3.1. Occurrence and concentration levels

According to literature and to the data collected in MINAGRIS project (Deliverable 3.3), the main acknowledge vehicles of MPN in agricultural soils can be:

- **Plastic waste remaining in the soil after use** (independently from their origin), AP accumulated and not removed from the farms. And in particular two sources were identified by the project: improperly removed films and common agriculture practices such as irrigation and use of compost coming from urban waste.
    - In case of improperly managed AP, the field and survey data underlined that significantly higher amounts of MaP items were found in those fields where plastic was used, both regarding the number of items per hectare, and when regarding the total weight of the MaP items
    - Concerning organic fertilizers: MINAGRIS project analyses the available data from soil analysis and results from growers' surveys and the presence of MNP is statistically correlated with the use of organic fertilizers (such as compost, manure, etc.) (Deliverable 3.3)
- **Intentionally added polymeric coating** typically used in controlled release fertilizers (CRFs) or seed coating are inevitable sources of MNP.

The analysis of field and surveys data also shows a correlation between the type of agriculture practice and crops and the presence of MNP; the highest concentration of MaP items was found in fields where vegetables were produced in greenhouses or covered cultivation practices, followed by fields with permanent crops and other vegetables. In these crops some of the AP used were classified by FAO (FAO, 2021) as the plastic items at highest risk of dispersion in the environment: ropes and clips for greenhouse crops, nets and protection nets for permanent crops.

So, while it appears that agricultural practices improperly managed AP can play a role and contribute to soil pollution, it appears difficult to fully comprehend the overall sources and clear role of other possible inputs and for sure this an aspect which needs further investigation.

Crops category does affect the amount of plastic residues in soils (especially in terms of MaP; fields with plastic intensive greenhouse vegetables resulted in a higher amount of MaP recovered.

According to the results of Deliverable 3.3 several agronomic practices introducing plastic debris in the agricultural soils were identified:

- Improperly removed mulch films.
- Common agricultural practices such as irrigation and urban compost.
- Intentionally added polymeric coatings typically used in controlled release fertilizers (CRF's) or seed coatings are an inevitably source of MNP's.

Other sources of MPN according to MINAGRIS results and to literature are identified as independent from the AP used. Tires, irrigation water, air deposit, which can be also related to the location of the farms. It has been underlined a clear link between type and quantity of MPN and geographical location, especially connected to urban areas (Boucard et al., n.d.). However, these sources are outside the scope and analysis of the projects.

Other relevant aspects related to the characteristics of plastics found in MINAGRIS analysis are reported below as illustrated in Deliverable 3.3:

- The main polymer found in form of MaP was PE, followed by PP, in agreement with the literature data on use of plastics in agriculture.
- The average number of MiP found was similar to other studies.
- Crop category and agronomic techniques.

Crop category affects the amount of plastic residues (MaP) found in the soil; larger amounts of MaP are recovered in fields where greenhouse vegetables are produced. These crops are plastic intensive resulting in higher amounts of plastic debris staying in the soil.

It is clear that the use of organic fertilizers as composts and sewage sludges increases the number of MiP particles quantified, overall, when those composts were obtained and applied in 1980's, when rules on composting quality were not strict regarding microplastic particles. And in those lands where sewage sludges are used as fertilizer it has been an exponential increase of microplastics in soils (e.g. van der Berg et al. 2020). It is worth noting that the non-biodegradable plastic residues persist in compost, while compostable materials (such as bags used for collection organic waste) can represent a solution to reduce the presence of non-biodegradable plastics and MiP. The results from a paper where different waste collection systems were compared (including door-to-door system using compostable bags) underlined that compost from big facilities from street bin collection displayed the highest contents of plastics. No debris from compostable bioplastics were found in any of the samples analysed in the study, where door-to door systems were in place using compostable bags, suggesting that the use of compostable polymers and the implementation of door-to-door collection systems could reduce the concentration of plastic impurities in compost (Edo, C. et al., 2021).

4. SURVEY ON THE KNOWLEDGE OF MICROPLASTICS IN AGRICULTURAL SOILS AND POSSIBLE WAYS TO REDUCE THEM

A survey to implement the knowledge on sources, effects and possible remediation measures was prepared and shared to a broader stakeholder audience (all active in the sector of agriculture , plastics and AP), including: national and European institutions, NGOs, industries (plastics and bioplastics producers and converters), industrial and agricultural associations (at Member State level and at European level) and academia. This tool aimed to gather information on the knowledge on use and end of life of plastics, available legislative instruments, good practices and techniques to minimize the production of microplastics in agricultural soil.

The survey was structured in 3 sections for a total of 33 questions, both open- and close-ended questions.

For the close-ended questions the **scores ranging from 1 (poor) to 5 (very positive).** For each question the average of the answers was calculated.

- **Part 1 – general data**: to collect general information on type of organization, where based (Europe, Member State) and main field of activity
- **Part 2 – State of art and knowledge gaps on microplastics and use of plastics in agriculture**, investigating the knowledge and data availability for plastics and MiP, and on legislative frameworks.
- **Part 3 – indicators for guidelines to reduce microplastics in soil**, investigating which can be considered feasible solutions to reduce the spreading of microplastics in the environment, with a particular focus on the plastic applications.

And an average time of about 12 minutes was required for surveys compilation. The survey was sent by e-mail to a selected list of stakeholders which was compiled trying to comprehend the different actors active in the entire value chain of AP production, use, end-of-life and legislators. It was accompanied by a letter which duly explained contest, aim and how to fill it in. The full questionnaire can be found in Annex 1.

A total of 34 stakeholders all around Europe were identified and reached by the survey. A total of 19 questionnaires were returned. Starting with these outputs the analysis presented in the following paragraphs was performed.

4.1. Analysis of data

4.1.1. General data

Out of 34 questionnaires distributed, a total of 19 complete responses were received.

In Table 3 the organizations are listed.

Name of Organization
Forschungsinstitut für biologischen Landbau Österreich (FIBL Austria) *
Irish Farm Film Producers Group (IFFPG)
TAMA Group
BASF SE
IK Industrieverband Kunststoffverpackungen e.V.
APE EUROPE
NETAFIM
Comité de la Plasticulture et de l'Agroenvironnement
European Commission Dg ENV
Plastics Europe °
DG Agri
Novamont
FARM EUROPE
Altereko Sas
European Bioplastics Association (EUBP)
FAO
Grupo AA

Table 3. Organizations that participated in the survey.

** Two questionnaires; ° two questionnaires*

The organizations participating in the survey are mainly from industry (6 out of 19) followed by other organizations and international organizations operating in the general area of agriculture, plastics and environment. The other categories represented are academia, institutions and national professional (Figure 6). The prevalent presence of industrial entities balances the need for practical solutions, direct knowledge of the market with the results obtained from the project and the feedback from the CSS surveys (mainly growers).

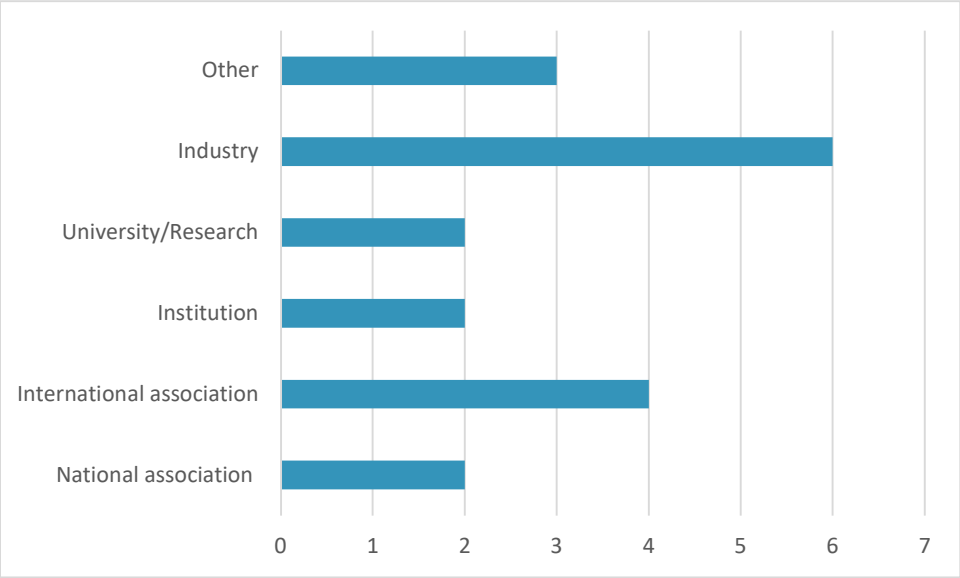

Figure 6. Types of organizations that participated in the survey.

The sample is **industry-heavy**, indicating strong engagement and interest from private companies. Public institutions appear limited at national level, but represented by key EU bodies (DG AGRI and DG ENV)

The field of operation and knowledge of the organizations ranges from plastic EoL to soil protection, giving a very appropriate and wide range of expertise in the area of use of plastics and agriculture (Figure 7).

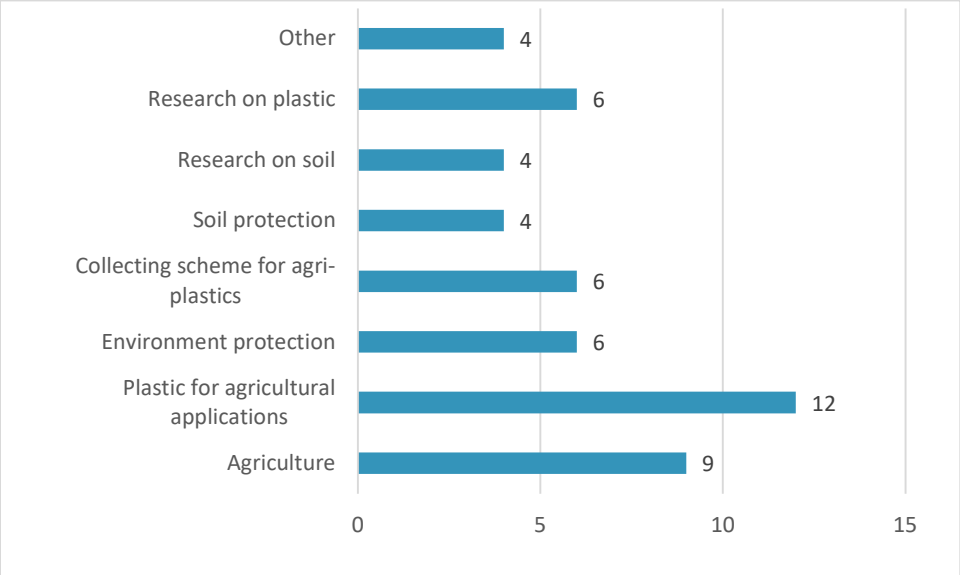

Figure 7. Area of expertise the organizations that participated in the survey.

About 26% of the respondents are based in Belgium, since many European organization have their headquarters in Bruxelles, but the area where agricultural plastics are mainly used are directly or indirectly represented: Italy, Spain, France, Germany.

The current stakeholder set provides a solid foundation in terms of industry and EU-level representation, but it would need to address better and try to engage more some sectoral and

geographic gaps, such as adding more representatives from national public authorities, from countries where APs are mainly used (e.g. Italy, Netherlands) and from Eastern Europe, including more NGOs and civil society. The low number of academia can be explained since the project itself is a research and innovation project and the output from the project are included in the considerations used to draft the Best Available Techniques (BATs).

4.1.2. State of the art and knowledge gaps on Microplastics and use of plastics in agriculture

Availability of data and statistics on use and end-of-life of agri-plastics and microplastics in soil

There is a strong consensus among the respondents that the data on the use of AP is limited (**average value 2.58**[3]), and those on the EoL are poor (**average value 2.47**). Almost all the stakeholders highlight that there is a lack of monitoring systems and absence of harmonized methodology for collecting and analyzing the data on use and end of life of plastics. Data on microplastics in soil is perceived as insufficient to be able to know the real pollution in different areas (**average value: 1,47**). Data collection both in terms of use and AP end-of-life as in microplastics monitoring is considered a **prerequisite for any effective policy or technical intervention.**

Possible sources of microplastics in agricultural soils

The respondents underline that a link between the usage of plastics in agriculture and presence of microplastics is present (average value of 3.32), but microplastics are not only derived by AP. The answers indicate different sources. The main sources are linked to an external dominant perspective: general sources (including tire abrasion, wind and water deposition), improper management and littering (**about 30 % of the respondents**). Another important source of contamination is related to a multiple-source perspective, where APs play a role when not properly removed (mulch films and irrigation tubes) – **about 23%** - as well as coated fertilizers and organic fertilizers (manure, sludges, compost, digestate). **Uncertainty and lack of consensus on origin** is a central issue.

In Germany over 13 ktons of plastics are in the environment every year. The main sources identified are sewage sludges, coated fertilizers and compost and digestates (NABU, 2021)

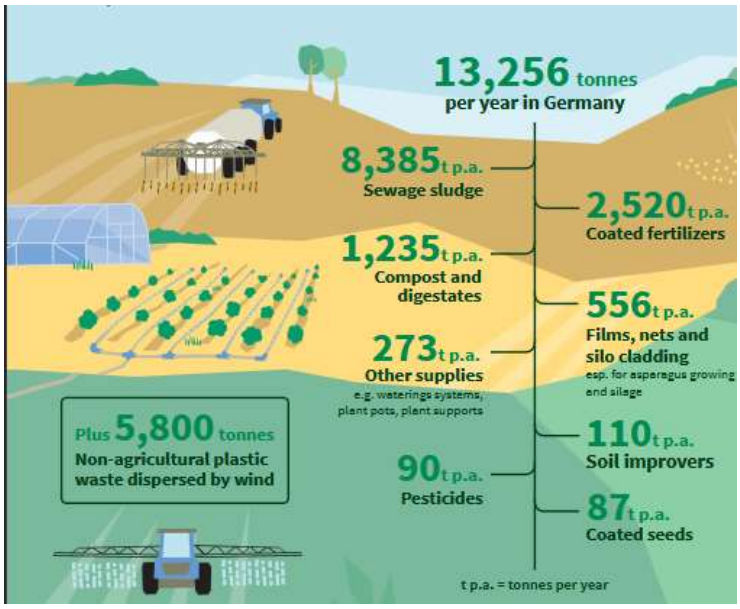

Figure 9. Sources of MPs in agricultural soils in Germany (NABU, 2021).

[3] Scores ranging from 1 (poor) to 5 (very positive). See Annex 1 for detailed questions and scales.

Which stage of plastic value chain is more impacting in terms of microplastics creation?

Most of the respondents underlined that the most impacting stage is the end-of-life (16 answers), followed by design (14 answers) and use (12 answers).

The core problems identified for the end-of-life management of plastics are both technical, economic and logistics. Lack of EPR schemes (majority of answers), lack of infrastructure for recycling , quality of agri-plastics at the end of the crop cycle, high contamination of plastics with soil and organic matter for some agri-plastics (a mulch film at the end of its use can have 3-4 times its weights in soil (APE EU, n.d.) together with the economic sustainability of recycling plant are identified as the main obstacles. The implementation of standardized national collecting schemes is another aspect of importance and also the need to properly involve and inform the growers is needed.

End-of-life of agri-plastics

If the end-**of-life management is the main leverage point to reduce contamination,** still implementations and organization as well as clear legislative framework are needed. Respondents underline a lack of homogeneity among the Member States in terms of presence of national collection schemes and infrastructures.

There is a consensus among the respondents that in Europe the AP waste is not properly managed (**average value 2,63**) for the reasons reported above.

The APs application recognized as more difficult to manage at the end of the use are mulch films, with a strong consensus - (especially the thin ones), agri-nets, twines and clips. These results are in line with the analysis reported by FAO (FAO, 2021), where these applications are in the upper part of the classification for plastics materials with potential dispersion in the environment.

The **costs involved** in the end-of-life management of agri-plastics waste are reported to be extremely variable depending on the location, type of plastic and type of infrastructure; many respondents did not know the costs involved. Nevertheless, some data was collected in the survey:

- In **Ireland IFFPG** (Irish Farm Film Production Group, https://farmplastics.ie/), the only plastic recycling compliance scheme reports that the plastic producers are charged 286 €/ton and the growers 100 €/ton per plastic waste
- In **France CPA** (*Comite de la Plasticulture et de l'agroenvironment* - https://www.plasticulture.com/) and Plastics Europe report an eco-contribution for APs waste ranging from 160-460 €/ton depending on the type of plastic products and if clean or not

It is underlined that where dedicated national schemes and EPR are present, APs can be properly removed and recycled. In Germany's ERDE voluntary framework initiative achieved 39,940 tons of recycled agricultural plastics in 2024. In France, ADIVALOR collected over 102 ktons of APs with a rate collection exceeding 70%; around 90% of the collected plastics is recycled reaching over 90 ktons of recycled APs (Par Guillaume P., 2026).

How to improve end-of-life of agri plastics and role of legislation

For those applications identified as most difficult to manage, the respondents indicated different possible solutions: use of alternative materials such biodegradable and compostable materials (especially to produce mulch films, nets and clips), increase mulch films' thickness to improve collection, improve materials quality (clean mulch film when removed). Again, the importance of having efficient national collection schemes and EPR is considered key, but it is underlined that recycling must be feasible and economic and implanting percentage of recycled material into new manufacts is important for the overall balance of the system. Other possible solutions are implementing farmers' training and information campaigns, promoting take-back campaigns, and improving eco-design of products.

Most respondents are aware that existing legislation on agri-plastics (only 2 out of 19 are not aware), waste management, soil protection and standards are still perceived as fragmented and only partially effective. The main recognized legislations and standards cited by the respondents are REACH microplastics restriction, FPR, EN standards (e.g. EN 17033), and national EPR schemes. Nevertheless, the implementation and enforcement gaps are perceived as more critical than the lack of legislation; an **average value of 2,61** is given to the efficiency of the existing legislative framework to mitigate the spreading and accumulation of microplastics in agricultural soil.

Solutions and mitigation strategies for microplastics in agricultural soils

The Stakeholders were requested to give 3 possible ways to reducing the presence of microplastics in agricultural soils. Use of biodegradable and compostable materials (when certified), improve waste management, particularly implementing National Collection Schemes and EPR and stricter and clear legislation are the 4 most suggested strategies. Again, important are improving knowledge and increasing awareness on microplastics. This underlines that much has to be done both in terms of research (specifically it was requested to have better monitoring of microplastics present in soil) and communication. Additional measures are banning problematic materials (e.g.: oxo-degradable materials), improve standard and promote good farming practices. (Figure 10).

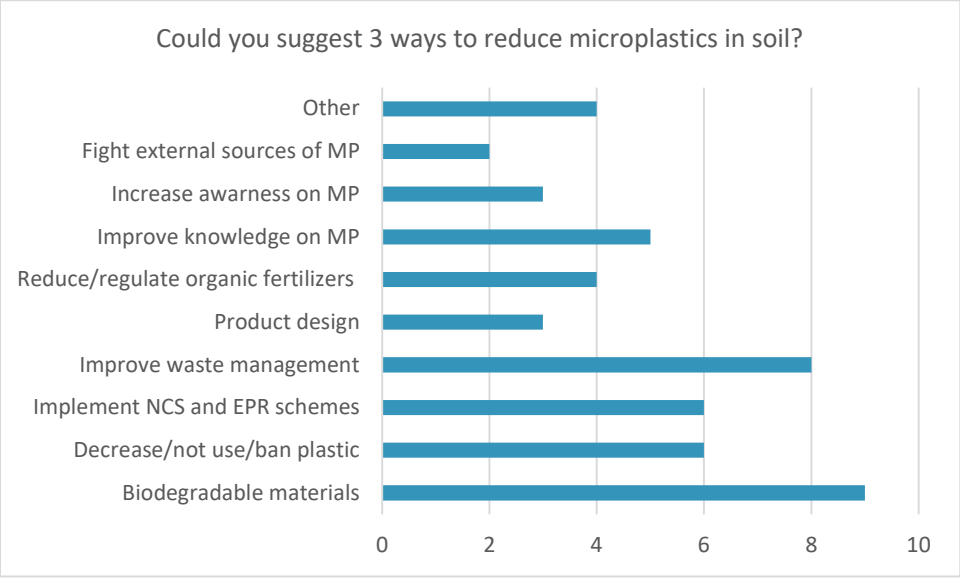

Figure 10. Possible ways to reduce MiP in soil are proposed by respondents.

A complex problem needs a systemic approach where all the aspects are to be considered: technical institutional (policies) and behavioral.

Alternatives to plastics

A mixed perspective on alternatives emerges in the answers. The respondents are not convinced that non-plastic alternatives can offer an effective way to reduce the potential of MiP contamination. The average score for the question was **2.63**.

Overall, there is a general consensus that biodegradable solutions can be beneficial and should be considered a solution or part of the solution, as reflected by an average score of **3.95**. More specifically, 8 out of the 17 respondents believe that biodegradable materials represent a viable solution. Others consider them only a partial solution highlighting limitations, such as the fact that biodegradation in the environment can depend on climatic conditions and the risk of contamination existing recycling streams if not properly managed.

The applications where biodegradable materials are considered a solution are mulch films and not recoverable applications (tree guards, coated seeds and fertilizers). The main concerns of the respondents are linked to the use of oxo-degradable materials and the lack of transparency regarding additives, and the harmless degradation products of this category of plastics. Again, there is no silver bullet in terms of solution, but an application-specific approach is necessary.

Reduction of plastic use: is this a solution?

There is a limited support for "reduction only" strategies (average score **2,74**), since plastics are considered essential in agriculture for productivity and food security. Plastics are helping in feeding the planet and with competitive costs. Modern agriculture is not possible without plastics. Furthermore, as already emerged in previous questions, microplastics are considered a more general problem with sources that are not strictly related to the use of agri-plastics; 11 of the 28 open-ended multiples answers are underlying that microplastics in agriculture soils might have a different origin. **A more efficient management of plastic waste can be beneficial to reduce the microplastics generated by agri-plastics**.

Governance and success factors

Since the legislative framework seems to be one of the weak points in relation to the management of plastics and in reducing MiP in the soil, we wanted to explore which possible implementations are considered as success factors (Figure 11).

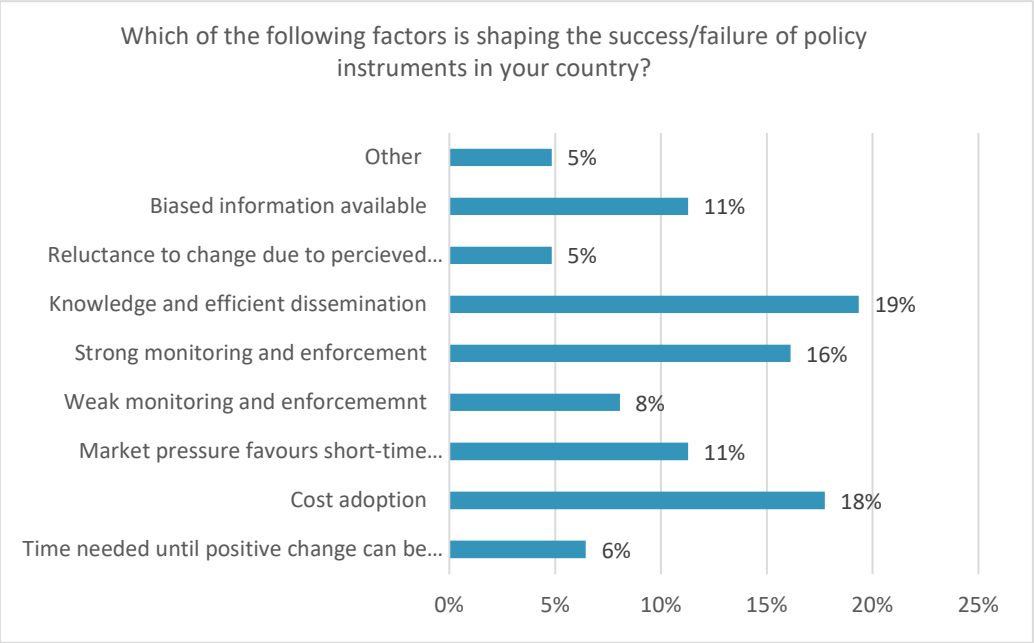

Figure 1. Which factors are considered to shape success/failure of policy instruments in the EU territories according to respondents.

Key of success factors are identified in: strong monitoring and enforcement of legislations, economic incentives, knowledge and dissemination and stakeholder engagement. On the other hand, the barriers are identified in: costs, market pressure, fragmented governance and lack of awareness.

Governance appears to be a critical limiting factor.

4.2. Stakeholders-based analysis

An analysis of the answer based on the type of stakeholders has been conducted, in order to evaluate the perception and the sensibility of different clusters of stakeholders. Stakeholders are divided into 4 categories: research, industry, associations (including EPR schemes) and policy.

First, we analyzed the different clusters' level of perception for data on plastics and microplastics availability and end-of-life (quantitative comparison), as reported by Table 4.

Stakeholder type	Data availability perception	End-of-life management perception
Research	Lowest (critical view)	Low
Industry	Moderate	Moderate
Associations	Moderate-high	Moderate-high
Policy	Higher	Higher

Table 4. Cluster analysis for different type of stakeholders. Perception on data availability for AP and MiP and EoL management as expressed by the survey's respondents.

A qualitative interpretation of the data gives us a better understanding of which aspects connected to the agri-plastic waste management and spreading of microplastic in soil are perceived by the different groups of stakeholders:

- **Industry**: the focus is on the technical feasibility of plastic management solutions and on their economic sustainability. The main focus of the industry is on EoL measures and a reduction in plastic use for the sector is not realistic. Possible solutions could be designing improvements and implementation in collection (NCS and EPR are mainly suggested). A pragmatic and system-oriented solution.
- **Associations / EPR schemes:** they pose a strong emphasis on collection systems and EPR, showing that systems where work were properly implemented. The concerns are related to a lack of EU-wide harmonization for collection and recycling, showing a most operational perspective on the problem.
- **Research /institutions:** they are the most critical stakeholders, underlying knowledge gaps and lack of scientific evidence and need of monitoring and standardization.
- **Policy stakeholders: m**ore balanced assessment. Focus on improving existing frameworks
- **Other stakeholders (FAO, consultants)** bear a more systemic and global view, underlying the microplastics multi-source contamination. A more holistic approach is needed.

In general, the key cross-cutting findings common to all the stakeholders are:

I. **Data gaps** represent a central bottleneck limiting policy effectiveness and preventing source attribution for microplastics in soil.
II. **End-of-life dominates system performance:** optimization of the end-of-life of agri-plastics could reduce the main source of leakage in the environment and represent the more urgent and main intervention area.
III. **EPR universally supported:** the adoption of EPR and national collection schemes for agri-plastics has the strongest consensus across all categories.
IV. Multiplicity of sources: there is also an agreement among the stakeholders that agri-plastics are not the only contributors to microplastics in soil and a systemic approach is required.
V. **No single technological solution:** there is no silver bullet. Different technologies and designs have to coexist in a holistic approach; design, reduction, recycling and biodegradable materials must coexist.

4.3. Discussion and conclusions

The survey highlights a **clear convergence among stakeholders** on the need for some key aspects:

- Improving data and monitoring systems for EoL of APs and MP in soil;
- Promoting strengthened and harmonized EPR schemes to better collect and dispose APs at the end of their use;
- Enhancing end-of-life infrastructure: a lack in infrastructure and technical solutions for recycling;
- Integrating eco-design principles to have the best and more suitable EoL in function to the use and characteristics of AP.

At the same time, it reveals a significant divergence in the perceived role of agriculture in microplastic pollution according to the type of stakeholder, a strong concern regarding economic and technical feasibility for EoL of plastic materials (especially concerning mechanical recycling).

Above all it emerges that there is no “silver bullet” single and universally applicable solution, but a strong effort by different areas and technical solutions along the whole value chain is required. A successful strategy to reduce microplastic emissions in agricultural soils must adopt a **life cycle, multi-stakeholder and system-based approach**, combining policy instruments, technological innovation, and behavioural change.

5. REGULATORY FRAMEWORK FOR PLASTICS IN AGRICULTURE

At European level the main instruments targeting broadly plastic pollution are summarized in Table 5.

A dedicated MINAGRIS deliverable - Deliverable 7.4 "Recommendations for policymakers in EU agriculture"- deeply analyzes the legislative framework in Europe dealing with use of plastics in agriculture. Nevertheless, it is important for the aim of this work to summarize the main policies dealing with plastics and MiP in force. (Table 3).

Document	General aspects regulated	Which AP is regulated	How
Regulation (EU) 2023/2055 (REACH) ("Commission Regulation (EU) 2023/2055 - Restriction of microplastics intentionally added to products - Internal Market, Industry, Entrepreneurship and SMEs," n.d.)	Intentionally added microplastics	Biodegradable and non-biodegradable plastics	Specific criteria are introduced for primary microplastics
Fertilizing Products Regulation 1009/2019 – Delegated acts: (EU) 2024/2787 and (EU) 2024/2788 ("Consolidated TEXT," n.d.) Delegated Acts: Reg (EU) 2024/2787, Reg. (EU) 2024/2770	Use of biodegradable polymers and biodegradable mulch films	Mulch films, fertilizers coating, water-retaining polymers	Requirements for biodegradability and ecotoxicity: criteria for biodegradability in soil and water (specific timeframe depending on application) and ecotoxicity in earthworms, plants and bacteria
Soil Monitoring Law (*Directive (EU) 2025/2360 of the European Parliament and of the Council of 12 November 2025 on soil monitoring and resilience (Soil Monitoring Law)*, 2025)	The EU Soil Monitoring framework identifies microplastics as priority contaminants for future monitoring harmonization	All agri-plastics contributing to microplastics in soil (secondary microplastics from mulch films, coatings, water-retaining polymers, and other agricultural plastic inputs)	Establishes a monitoring and assessment framework (not direct restrictions), requiring standardized methods for measuring microplastics in soil, harmonized indicators, and data collection to support future risk assessment and regulatory action

Standard EN 17033 (CEN, 2018)	On biodegradable mulch films	Biodegradable mulch films used in agriculture	Defines requirements for biodegradation in soil (conversion to CO_2 within a specified timeframe), disintegration (no visible residues after a defined period), ecotoxicity (no adverse effects on soil organisms such as plants and earthworms), and limits on heavy metals; also sets technical performance criteria for mulch films
EN 13432:2002 (Standards, n.d.)	Requirements for packaging recoverable through composting and biodegradation Biodegradable plastics used in packaging (including films and compostable materials)	Defines criteria for biodegradability (conversion to CO_2 within a specified timeframe), disintegration during composting, limits on heavy metals, and ecotoxicity tests to ensure no negative effects on compost quality	Definition of biodegradability criteria, limits for heavy metals and ecotoxicity tests to have materials which can be fully composted in an industrial composting plant

Table 5. Main European policies dealing with AP (conventional and biodegradable) and microplastics in soil.

6. IDENTIFIED KNOWLEDGE GAP FOR AGRI-PLASTICS AND MICROPLASTICS

Identifying knowledge gaps related to use and EoL of agri-plastics as well as presence, effects and monitoring of MiP is a fundamental aspect to help and design the Best Available Technologies (BATs) with the aim to reduce the spreading of MiP in agricultural soils. The main knowledge gaps emerged by MINAGRIS technical deliverables (Deliverable 3.3), CSS questionnaires to growers and growers' organizations (Deliverable 8.2) and from the stakeholder's survey presented in this document (Chapter. 4) are reported below.

I. Lacking figures of AP market in Europe

While the amounts of virgin plastics sold to converters in Europe and placed in the market for agricultural applications are available, recycled quantities are missing. Also missing are the total volumes of finished products (films, rope, etc.) entering the farms and used in the fields.

Data on the use and types of biodegradable plastics per application and per EU country is missing or scarce, as well as the data on the presence of oxo-degradable plastics in the market, even though, in the last 10 years, investigations regarding microplastics in the agricultural systems have shown residues of PE oxo-degradable in soil, applied 20 years ago (named as PAC in several publications, e.g.: Scopetani et al. 2024; Huerta Lwanga et al. 2023).

For all the topics mentioned above, the geographical distribution either per country or per region is completely lacking in public figures. The stakeholders' surveys carried out within MINAGRIS projects support this knowledge gap.

II. Lack of figures on common practices, waste management and agri-plastics EoL

As previously underlined, only the data on EoL of AP in some Member States are available, where national collecting schemes are in place. For some applications (clips, wire, nets, tree shelters) the data on the EoL are missing even though it is reported that they might be mismanaged in the field (EUNOMIA, 2021). According to the data collected via interviews with farmers it appears that no or scarce access to advice or information regarding best practices for agri-plastics is available (Deliverable 8.2, MINAGRIS Project).

III. Lack of knowledge on relationship between plastic use - microplastics formation and accumulation

It appears that the relationship between use, common practices and accumulation of microplastics in soil is not evident, even though some examples have been seen using sewage sludge in Spain (van der Berg et al. 2020). This emerges both from the stakeholder's survey and from the surveys conducted by the CSS leaders (Deliverable 8.2, MINAGRIS Project).

7. BEST AVAILABLE TECHNIQUES TO REDUCE MICROPLASTICS IN AGRICULTURAL SOIL

Based on the previously described analysis, data and references, **7 Best Available Techniques** (BATs) are proposed. Future BAT frameworks should integrate harmonized monitoring, environmental indicators, source-specific risk assessment. The 7 proposed BAT are listed and summarized in Table 4.

For each BAT the following aspects will be reported:

- Primary target: who can be directly engaged and operate the BAT (growers, institutions, researchers, etc.),
- General description of the BAT,
- Enabling factors: which elements/factors can facilitate the adoption of BAT,
- Technical considerations: which factors should be prioritized in the adoption of BAT from a technical point of view,
- Relevance for MNP production: how the BAT can reduce the dispersion of MNP in soil,
- Relevant examples already in place, representative of BAT.

FAO has elaborated an advanced circular model that goes beyond traditional waste management approaches (so called “3R model: Reduce, Reuse, Recycle). The “6R framework” (Refuse, Redesign, Reduce, Reuse, Recycle, Recover) integrates prevention, design, and end-of-life strategies This approach integrates design and production and not only EoL in a life-cycle thinking. It also takes into consideration food safety, crop productivity and agriculture resilience and includes measures to prevent plastic fragmentation and reduce MiP release in soil (FAO, 2021).

BAT	PRIMARY TARGET	GENERAL DESCRIPTION	RELEVANCE FOR MiP REDUCTION	BEST PRACTICES/APPLICATIONS
BAT 1 - Reduce plastic use	Agricultural operators	Minimize the use of single-use plastics, optimize material efficiency and prioritize reusable and long-life solution	Reduce plastic leakage, reduce fragmentation, decrease production of plastic waste, improve collection and recycling	A. NL - Reusable greenhouse and horticulture systems in the Netherlands B. EU -EIP-AGRI initiatives to reduce plastic footprint
BAT 2 – Dedicated collection and traceability systems	Agricultural operators, waste management operators, producer responsibility organizations, manufacturers and public authorities	Implementation of dedicated collection and traceability systems for APs management to minimize environmental leakage and the formation of MNPs at field level	Efficient collection and traceability systems are considered essential measures for reducing secondary microplastic formation from agricultural plastic waste streams	A. France – A.D.I.VALOR national collection scheme for APs B. Germany – ERDE national collection system for APs C. EU -APE Europe initiatives on agricultural plastics recycling
BAT 3 – Avoid improper disposal	agricultural operators (growers, technical advisors), waste managers, local authorities	Avoid improper management of agri-plastics including open burning, uncontrolled burial, illegal dumping, and informal disposal of agricultural plastics and related materials	Prevention of secondary microplastic formation by lowering the persistence of APs in the environment, reduction of airborne microplastic emissions and soil	A. France – A.D.I.VALOR B. Italy and Germany - National bans on open burning of agricultural waste

			contamination from fragmented plastic residues, prevention of plastic leakage into rivers and drainage systems	C. Finland and Sweden - Mobile collection services for APs in rural areas
BAT 4 – Improve recycling quality and circularity	Agricultural operators (growers and technical advisors), recyclers, plastic producers, waste management operators, policy makers	Improve the quality, traceability, and circularity of agricultural plastic waste streams through source segregation, contamination reduction, dedicated recycling systems, and eco-design approaches that facilitate recyclability and material recovery	Improving recycling and quality of APs results in reduction of losses during collection and processing, minimizing fragmentation and secondary MiPs generation; supporting circular economy approaches, increasing the use of recycled materials in agricultural supply chains	A. Germany – ERDE agricultural film recovery program B. France – A.D.I.VALOR C. EU – Operating EU schemes for managing APs griculture, Plastiques & Environement," n.d.) D. Finland/Sweden - Mobile collection services for APs in rural areas
BAT 5 – Use certified biodegradable mulch films (EN 17033 or FPR 1009/2019)	Agricultural operators, horticultural producers, plastic manufacturers, agricultural advisors, policy makers	For agricultural applications where retrieval of conventional plastic mulch films is technically difficult, economically impractical, or associated with high environmental leakage risks, certified biodegradable mulch films compliant with EN 17033 or certified as fertilizers.	Reduction of persistent plastic residues in agricultural soils, since biodegradable mulch films eliminate secondary MiP generation) and therefore reduce long-term soil contamination. Reduced waste management burdens, while lowering environmental	A. Commercial use of biodegradable mulch for horticulture B. FAO - biodegradable mulch films C. FAO Recommendation for plastics use in agriculture

			leakage associated with retrieval operations.	
BAT 6 – Promote biodegradable coatings for fertilizers (in compliance with FPR 1009/2019)	Fertilizer manufacturers, agricultural operators, distributors, policy makers, agricultural advisors.	Controlled release fertilizers are covered with non-biodegradable polymers, which are left in the soil (impossible to remove) and accumulate MiP. Since 2024 requirements for biodegradable polymers were introduced via Delegated Act in the EU FPR, to eliminate this source of pollution. FPR requires that by 2028 non-biodegradable coating will be substituted with biodegradable ones	Reduction of persistent polymer accumulation in soils, lower generation of secondary microplastics, reduced long-term agricultural soil contamination, lower diffuse plastic inputs from fertilization practices, improved sustainability of controlled-release fertilizers, promotion of circular and bio-based agricultural inputs.	A. Recent EU regulation framework: FPR, Soil Monitoring low B. FAO recommendation for plastic use in agriculture
BAT 7 – Compostable accessories for horticulture in compliance with international standards (EN 13432)	Horticultural producers, greenhouse operators, agricultural cooperatives, composting operators, manufacturers of agricultural accessories	Compostable horticultural accessories such as clips, twines, ties, hooks, plant support materials, and fastening systems represent ways of reducing plastic contamination in agricultural organic waste streams and limiting the generation of persistent MNPs especially for those applications difficult to remove and at risk of dispersion/mismanagement	Reduction of persistent plastic residues in composting systems, lower contamination of organic amendments; reduced fragmentation of horticultural plastics; prevention of secondary MiP generation; improved quality of compost and digestate;	A. NL – use of compostable clips and twines B. ES –use of compostable clips and twines and supporting CAP measures C. Belgium - Industrial composting integration projects

			lower environmental leakage from mixed waste streams; improved circularity of horticultural waste management	

Table 6. BATs: primary targets, general description of BAT, relevance in terms of MiP reduction, which main best practices already in place.

7.1. BAT 1 – Reduction of unnecessary agri-plastic use

PRIMARY TARGET: agricultural operators.

DESCRIPTION: Agricultural operators should minimize avoidable single-use plastics, optimize material efficiency, implement precision agriculture approaches, and prioritize reusable or longer-life systems where technically and economically feasible. This BAT aims to reduce the generation of plastic waste and the subsequent formation of MNPs in soil and surrounding ecosystems through prevention measures applied at farm level. The approach follows the "smarter use of plastics" pathway identified by the and the circular management principles promoted by the European Environmental Agency ("Pathways towards circular plastics in Europe — good practice examples from countries, business and citizens," 2023) and as recommended by FAO Voluntary Code of Conduct for the Sustainable Use and Management of Plastics in Agriculture (*A Provisional Voluntary Code of Conduct on the Sustainable Use and Management of Plastics in Agriculture*, 2025) in which prevention, reduction and optimized use are identified as priority actions for agricultural systems.

ENABLING FACTORS: implementation of BAT 1 can be facilitated by farmer training and advisory services, economic incentives under CAP, national agricultural plastic collection systems, availability of reusable and durable alternatives, precision agriculture technologies, standards and certification schemes, EPR (Extended Producer Responsibility) systems, access to biodegradable alternatives for critical applications, harmonized guidance documents and voluntary codes of conduct and implementing the use of MINAGRIS Decision Support Tool (specifically formulated for mulch film).

TECHNICAL CONSIDERATIONS: BAT 1 should prioritize the following hierarchy :

- Avoid unnecessary plastic use;
- Reduce material intensity;
- Reuse durable systems;
- Optimize product lifespan;
- Improve collection and recycling;
- Use certified biodegradable solutions only where prevention/reuse are not feasible.

RELEVANCE FOR MNP REDUCTION : This BAT directly contributes to reduction of plastic leakage, lower fragmentation of agricultural plastics, decreased secondary microplastic generation, lower waste management burdens, reduced contamination of soils and water bodies. Prevention-oriented measures are considered among the most effective long-term strategies for reducing MNP emissions in agricultural ecosystems.

EXAMPLES OF BEST AVAILABLE PRACTICES IN EUROPE

A. Netherlands - Reusable greenhouse and horticulture systems

Netherlands – circular greenhouse horticulture: Dutch greenhouse horticulture increasingly promotes the reusable growing systems, reusable trays and containers, durable greenhouse films, reusable transport packaging, compostable or reusable clips and twines.

The "circulaire glastuinbouw" approach supported by Dutch horticultural programs focuses on extending product lifetime and reducing disposable plastics ("Smarter use of plastics promotes circular agriculture and horticulture," n.d.) ("Navigating Volumes and Value Chains," n.d.)

Examples include reusable crate systems, closed-loop transport packaging, centralized collection and reuse logistics.

B. EU - EIP-AGRI initiatives to reduce plastic footprint

The EIP-AGRI Focus Group "Reducing the plastic footprint of agriculture" identified several operational good practices. Among these: optimization of much thickness to reduce the leakage of plastics in soil, reuse of silage films, reduction of over-packaging, precision fertilization, reusable crop protection systems, biodegradable solutions where retrieval is difficult and risk of dispersion in the environment.

The report emphasizes that prevention and smarter use should always have priority over end-of-life management (EIP-AGRI, 2021)

7.2. BAT 2 – Dedicated collection of APs and traceability systems

PRIMARY TARGET: Agricultural operators, agricultural cooperatives, waste management operators, producer responsibility organizations, manufacturers and public authorities**.**

DESCRIPTION: Dedicated collection and traceability systems should be implemented to ensure the proper management of agricultural plastics throughout their lifecycle and to minimize environmental leakage and the formation of MNPs.

Best practices include farm-level segregation, certified collection infrastructures, traceability schemes, take-back systems and Extended Producer Responsibility (EPR) mechanisms**.**

This BAT aims to improve collection efficiency, increase recycling quality, reduce uncontrolled disposal and prevent fragmentation of plastics into soils and surrounding ecosystems**.**

ENABLING FACTORS: Implementation of BAT 2 can be facilitated by national EPR legislation, dedicated agricultural plastic collection schemes, farmer awareness and training, harmonized waste classification systems, digital traceability tools, regional collection centres, financial incentives and eco-fees, collaboration between farmers, cooperatives and recyclers, technical standards for recyclability, and mandatory reporting systems.

The identified traceability and dedicated collection systems are among the key measures necessary to reduce agricultural plastic leakage into the environment.

TECHNICAL CONSIDERATIONS : Effective implementation of BAT 2 requires segregation at source, minimization of soil contamination, separate collection of incompatible polymers, farmer education, accessible collection infrastructure.

Priority should be given to applications with high leakage risks, high fragmentation potential and difficult recovery conditions. These include mulch films, drip irrigation tapes, silage films, greenhouse covers, horticultural accessories.

The Eunomia report for the European Commission identified agricultural films contaminated with soil and organic residues as one of the most problematic plastic streams for conventional recycling systems. (ec.europa.eu).

RELEVANCE FOR MNP REDUCTION : BAT 2 contributes directly to reduction of plastic leakage into soils, prevention of environmental fragmentation, improved recycling quality, lower uncontrolled disposal, reduced open burning practices, increased circularity of agricultural plastics.

Efficient collection and traceability systems are considered essential measures for reducing secondary microplastic formation from agricultural plastic waste streams.

Best practices include:

- farm-level segregation,
- certified collection infrastructures,
- traceability schemes,
- take-back systems,
- EPR mechanisms.

Particular attention should be given to all APs used and specifically to those types of APs which are more “contaminated” at the end of their use.

EXAMPLES OF BEST AVAILABLE PRACTICES IN EUROPE

A. **France: A.D.I.VALOR national agricultural plastic collection scheme** (“A.D.I.VALOR - Agriculteurs, Distributeurs, Industriels pour la VALORisation des déchets agricoles,” n.d.)

France has developed one of the most advanced agricultural plastic collection systems in Europe through. The system includes farm-level segregation, dedicated collection points, take-back systems, traceability mechanisms, partnerships with manufacturers and recyclers.

Collected materials include mulch films, greenhouse films, irrigation pipes, fertilizer bags, silage films, nets and twines.

The scheme reportedly achieves collection rates exceeding 70% for several agricultural plastic streams and is widely recognized as a European best practice.

B. GERMANY - ERDE agricultural film recovery program (ERDE, n.d.) **(**erde-recycling.de)
Germany operates the voluntary recovery initiative for agricultural plastics. The program covers: silage films, stretch films, greenhouse plastics, nets and twines. Best practices include dedicated collection logistics, quality requirements for recyclability, farmer guidance on contamination reduction, and reporting systems.

The initiative supports high-quality recycling through cleaning requirements, source separation, standardized collection procedures.

B. **EU -APE Europe initiatives on agricultural plastics recycling (apeeurope.eu)**
APE Europe promotes harmonized collection schemes, traceability approaches, quality standards for recycled agricultural plastics, EPR systems, circularity targets.

APE Europe highlights that agricultural plastics differ substantially from household plastics because of high contamination levels, mixed polymer streams, seasonal generation, rural logistics constraints.

The organization supports development of dedicated infrastructure, best practice guidelines, and standardized recycling criteria.

7.3. BAT 3 – Avoid improper disposal of agricultural plastics (including open burning)

PRIMARY TARGET: agricultural operators (growers, technical advisors), waste managers, agricultural cooperatives, local authorities.

DESCRIPTION: Agricultural operators should avoid improper management of agri-plastics including open burning, uncontrolled burial, illegal dumping, and informal disposal of agricultural plastics and related materials. Agricultural plastics should instead be managed through authorized collection, recycling, recovery, or certified treatment systems (BAT 2).

Open burning agricultural plastics is considered a major source of environmental pollution because incomplete combustion generates toxic emissions and contributes to the formation and dispersion of MNPs into soils, water bodies, and the atmosphere.

This BAT aims to reduce direct release of plastic debris into agricultural environments, formation of secondary microplastics from degraded residues, airborne transport of plastic particles, contamination of soils and aquatic ecosystems, risks to human health and biodiversity. This approach is consistent with the waste hierarchy principles promoted under the European Union waste legislation ("EU waste management law | EUR-Lex," 2008) and with the recommendations included in the FAO Voluntary Code of Conduct for the Sustainable Use and Management of Plastics in Agriculture (2025), which identifies uncontrolled disposal and open burning as practices to be phased out (*A Provisional Voluntary Code of Conduct on the Sustainable Use and Management of Plastics in Agriculture*, 2025).

ENABLING FACTORS : Implementation of BAT 3 can be facilitated by: availability of dedicated agricultural plastic collection schemes, accessible rural waste management infrastructure, Extended Producer Responsibility (EPR) systems (OECD, 2024), farmer awareness and training programs, enforcement of national environmental legislation, economic incentives for proper collection and recycling, cooperative-based collection logistics, traceability systems for agricultural plastics, local recycling facilities for agricultural films and packaging, harmonized guidance documents on safe disposal practices, mobile or seasonal collection services in remote agricultural areas. The FAO guidance emphasizes that effective collection and environmentally sound waste management are essential to prevent agricultural plastics from becoming a source of microplastic contamination (*A Provisional Voluntary Code of Conduct on the Sustainable Use and Management of Plastics in Agriculture*, 2025)

TECHNICAL CONSIDERATIONS : BAT 3 should prioritize the following hierarchy: prevent uncontrolled disposal and littering, prohibit open burning of agricultural plastics, ensure separate collection of agricultural plastic waste, promote recycling and material recovery where feasible, use certified disposal or energy recovery systems only for non-recyclable fractions, improve traceability and monitoring of plastic waste flows.

Uncontrolled burial or abandonment of plastics in agricultural soil should also be avoided because long-term fragmentation contributes to secondary microplastic generation and persistent soil contamination. Particular attention should be given to those APs which are more difficult to collect and recycle and more at risk of dispersion/mismanagement in the environment (such as: mulch films, bale wraps and twines, silage films, fertilizer and pesticide packaging). Contaminated agricultural plastics should be cleaned and sorted where technically feasible to improve recycling potential and reduce environmental leakage.

RELEVANCE FOR MNP REDUCTION : BAT 3 directly contributes to the prevention of secondary microplastic formation by lowering the persistence of APs in the environment, reduction of airborne microplastic emissions and soil contamination from fragmented plastic residues, prevention of plastic leakage into rivers and drainage systems, while improving circular management of agricultural plastics.

Avoiding open burning is considered a high-priority prevention measure because combustion residues and partially degraded plastics may become an important source of environmental MNP contamination. Proper collection and controlled waste management significantly reduce the risk of long-term accumulation of plastic particles in agricultural ecosystems.

EXAMPLES OF BEST AVAILABLE PRACTICES IN EUROPE

A. **France - Agricultural plastic collection systems - A.D.I.VALOR** ("A.D.I.VALOR - Agriculteurs, Distributeurs, Industriels pour la VALORisation des déchets agricoles," n.d.)

B. **Italy/Germany - National bans on open burning of agricultural waste**

   Environmental regulations in several European countries prohibit open burning plastic waste, including agricultural plastics. **In Italy**, open burning of agricultural residues is generally restricted under Legislative Decree No. 152/2006 ("DECRETO LEGISLATIVO 3 aprile 2006, n. 152 - Normattiva," n.d.), which establishes a general prohibition on open burning of waste and allows only limited exceptions under strict conditions; additional regional measures often introduce seasonal bans and further restrictions. In **Germany**, open burning of agricultural residues has been prohibited by law since 1990, with only rare exemptions, reflecting stringent air quality and waste management policies ("sector:agriculture:start [German Informative Inventory Report]," n.d.).

C. **Finland/Sweden - Mobile collection services for APs in rural areas**

   Remote rural regions have introduced mobile collection systems for agricultural plastics, including seasonal farm collection campaigns, cooperative transport schemes, centralized sorting hubs. These approaches reduce the on-farm accumulation of waste plastics, illegal dumping in forests or rural areas, and environmental fragmentation of abandoned plastics.

   Finland: mobile collection for AP in rural areas (EU CAP NETWORK, n.d.) ("Finnish Agricultural Plastics Recycling Ltd," n.d.).

   Sweden: national EPR scheme for agricultural plastics with seasonal collection campaigns (adminxxl, n.d.).

7.4. BAT 4 – Improve recycling quality and circularity

PRIMARY TARGET: agricultural operators, recyclers, plastic producers, waste management operators, policy makers.

DESCRIPTION: Agricultural operators and relevant stakeholders should improve the quality, traceability, and circularity of agricultural plastic waste streams through source segregation, contamination reduction, dedicated recycling systems, and eco-design approaches that facilitate recyclability and material recovery. Agricultural plastics are often difficult to recycle because they are contaminated by soil, organic matter, pesticides and fertilizers, moisture, mixed polymer fractions (EUNOMIA, 2021).

The approach is aligned with various legislative frameworks and recommendations the EU Circular Economy Action Plan ("Circular economy action plan - European Commission," n.d.), the European Environment Agency (EEA) recommendations on circular plastics ("Plastics, the circular economy and Europe's environment," 2021), the FAO Voluntary Code of Conduct for the Sustainable Use and Management of Plastics in Agriculture (*A Provisional Voluntary Code of Conduct on the Sustainable Use and Management of Plastics in Agriculture*, 2025), the EU Plastics Strategy ("EUR-Lex - 52018DC0028 - EN - EUR-Lex," n.d.), EIP-AGRI recommendations on reducing the plastic footprint of agriculture (EIP-AGRI, 2021).

ENABLING FACTORS : Dedicated agricultural plastic collection schemes, farmer training on segregation and cleaning practices, harmonized recycling standards, eco-design requirements for agricultural plastics, Extended Producer Responsibility (EPR) systems, investments in recycling infrastructure, digital traceability systems, public-private partnerships development of markets for recycled agricultural plastics, standardized labeling systems for polymer identification, research and innovation in recyclable and mono-material products, quality certification schemes for recycled materials.

TECHNICAL CONSIDERATIONS : Recommended technical measures include separate collection of different plastic fractions, removal of excessive soil and organic residues before storage, avoiding mixing agricultural plastics with municipal or hazardous waste, use of standardized polymer types where feasible, reduction of multi-layer or difficult-to-recycle materials, adoption of reusable transport and storage systems, implementation of product labeling for recycling compatibility, design of agricultural plastics with longer service life and recyclability in mind.

Eco-design approach is particularly important and should consider some technical aspects such as simplified polymer composition, reduced additive complexity, compatibility with existing recycling technologies, durability and repairability, minimization of hazardous additives.

Dedicated recycling streams for agricultural plastics may significantly improve material recovery efficiency, recycled material quality, economic viability of recycling and reduce the plastic leakage.

RELEVANCE FOR MNP REDUCTION: Poor-quality collection and contamination reduce recycling efficiency, increase disposal rates, and contribute to leakage of plastic residues and MNPs into agricultural ecosystems. Improving recyclability of APs, leading to reduction of losses during collection and processing, minimizing fragmentation and secondary MiPs generation, support circular economy approaches, increase the use of recycled materials in agricultural supply chains. Higher-quality recycling systems reduce the probability that agricultural plastics become unmanaged waste sources that fragment into microplastics in agricultural environments.

EXAMPLES OF BEST AVAILABLE PRACTICES IN EUROPE

A. **Germany – ERDE agricultural film recovery program** (ERDE, n.d.)
B. **France – A.D.I.VALOR.**
C. **EU – Operating EU schemes for managing APs** ("Operating schemes - APE Europe - Agriculture, Plastiques & Environement," n.d.)**.**
D. **Finland/Sweden - Mobile collection services for APs in rural areas.**

7.5. BAT 5 – Use of certified soil-biodegradable mulch films (EN 17033 or/and FPR 1009/2019)

PRIMARY TARGET: agricultural operators, horticultural producers, plastic manufacturers, agricultural advisors, policy makers.

DESCRIPTION: For agricultural applications where retrieval of conventional plastic mulch films is technically difficult, economically impractical, or associated with high environmental leakage risks, certified biodegradable mulch films compliant with EN 17033 or certified as fertilizers may represent a Best Available Technique (BAT). Conventional polyethylene mulch films can be difficult to completely remove from soils (especially thin ones), particularly in intensive horticulture, small-scale fragmented farming systems, mechanically challenging soils, high-moisture environments, long growing cycles.

Incomplete retrieval of conventional plastics may lead to accumulation of plastic residues in soil, fragmentation into MNPs, long-term soil contamination, increased waste management burdens.

Certified soil-biodegradable mulch films are designed to biodegrade in soil **under defined environmental conditions**, thereby reducing the persistence of plastic residues, and minimizing the risk of long-term accumulation when properly managed. The main standard and legislative references are: standard EN17033 (CEN, 2018) and Fertilizing Product Regulation (European Parliament, European Council, 2019)

The approach is consistent with various legislative and orientation documents: EU Policy Framework on Biobased, Biodegradable and Compostable Plastics (European Commission, DG Environment, n.d.), FAO Voluntary Code of Conduct for the Sustainable Use and Management of Plastics in Agriculture (*A Provisional Voluntary Code of Conduct on the Sustainable Use and Management of Plastics in Agriculture*, 2025), European Green Deal objectives (European Commission, 2019), EU Circular Economy Action Plan ("Circular economy action plan - European Commission," n.d.), EU FPR Regulation 1009/2019 (European Parliament, European Council, 2019).

The European Commission identified agricultural mulch films among the priority applications where biodegradable plastics can provide environmental benefits due to the high difficulty of complete retrieval after use.

ENABLING FACTORS: availability of certified EN 17033 biodegradable mulch films or biodegradable mulch films in conformity with FPR requirements for biodegradable mulch films (necessity for converters to certify mulch films in accordance with standards and FPR), farmer training on proper application and soil management, clear certification and labeling systems, technical guidance on suitable crop and soil conditions, research and innovation programs, public incentives for sustainable agricultural practices, harmonized EU standards and conformity assessment systems, advisory services supporting transition from conventional films.

The FAO guidance recognizes biodegradable mulch films as a potentially valuable solution for selected agricultural applications where prevention, reuse, or complete retrieval of conventional plastics are not feasible.

TECHNICAL CONSIDERATIONS: BAT 5 should prioritize the use of certified biodegradable mulch films especially in applications where retrieval rates of conventional plastics are low, contamination

prevents effective recycling, soil conditions increase fragmentation risks, environmental leakage is likely, reusable alternatives are not technically feasible.

Biodegradable mulch films used under BAT 5 should comply with EN 17033 or FPR requirements, be suitable for the specific crop and climatic conditions, be correctly incorporated into soil management practices. Furthermore, it is important that certification by recognized conformity assessment systems, existing agricultural machinery are compatible with biodegradable mulch films, proper storage and handling are followed.

RELEVANCE FOR MNP REDUCTION: BAT 5 directly contributes to reduction of persistent plastic residues in agricultural soils, since biodegradable mulch films eliminate secondary MiP generation and therefore reduce long-term soil contamination. In addition to this BAT 5 reduces waste management burdens, while lowering environmental leakage associated with retrieval operations. Overall, an improved sustainability of agricultural mulching systems can be achieved.

Compared with conventional polyethylene mulch films, certified biodegradable alternatives may substantially reduce the risk of persistent plastic accumulation where complete retrieval cannot realistically be achieved. The use of properly certified biodegradable mulch films may therefore represent an important upstream prevention strategy for reducing agricultural microplastic pollution in selected applications.

ACTUAL LIMITATIONS

Under certain environmental conditions, particularly in regions where soil temperatures remain below 15 °C during the summer season, the biodegradation of materials in soil may be slower compared to warmer Mediterranean climates. This reduced degradation rate can lead to a prolonged persistence of biodegradable materials.

For this reason, preliminary field trials should be conducted under representative local conditions to accurately assess the real biodegradation dynamics. These trials should take into account site-specific factors such as soil type, moisture content, microbial activity, and agricultural practices, which may all influence degradation performance.

In such contexts it could be recommended the use of biodegradable films to one application per growing season.

CALL FOR INNOVATION

The evaluation of interactions between biodegradable materials and other environmental stressors—such as pesticides, fertilizers, antibiotics, or other agrochemicals—requires the adoption of validated and standardized methodologies. At present, there is a clear need to develop a harmonized methodological framework that enables reliable and reproducible assessment of these interactions and their effects on soil ecosystems and biodegradation processes.

Such a framework should be designed to avoid common experimental biases and artifacts, including:

- the use of unrealistic mixtures of active substances (e.g. pesticide cocktails that do not reflect actual agricultural applications),

- insufficient experimental design, particularly the lack of appropriate positive and negative controls, which are essential for correct data interpretation,
- non-standardized test conditions that limit comparability across studies.

In parallel, further research and innovation should focus on improving the performance of certified biodegradable materials under suboptimal environmental conditions, particularly in soils with lower temperatures. This may involve:

- the optimization of new formulations or polymer blends with enhanced biodegradability,
- the incorporation of additives or enhancers that promote microbial activity,

Overall, these innovation efforts should aim to ensure that biodegradable materials maintain both their functional performance in agricultural applications and their environmental compatibility across a wide range of conditions.

EXAMPLES OF BEST AVAILABLE PRACTICES

A. Europe - Use of certified biodegradable mulch films in horticulture

Several European experiences demonstrate that certified soil-biodegradable mulch films can represent a practical and commercially viable solution in agricultural systems where retrieval of conventional polyethylene (PE) mulch films is technically difficult, economically burdensome, or associated with a high risk of environmental leakage. Commercial use of certified biodegradable mulch films has been established for more than two decades in Mediterranean horticulture, particularly in Italy and Spain, where they are widely applied in processing tomato, melon, zucchini, strawberry, and other vegetable production systems (Cozzolino et al., 2023; Tofanelli and Wortman, 2020). These applications have shown that certified biodegradable films can provide agronomic performances comparable to PE mulches while eliminating the need for post-harvest retrieval operations and reducing the risk of persistent plastic residues in soil (Scarascia-Mugnozza et al., 2006; Moreno et al., 2017, (Panagos et al., 2025)).

The current Common Agricultural Policy (CAP) 2023–2027 actively supports the transition towards these alternatives. Under the Spanish fruit and vegetable sector intervention, Royal Decree 857/2022 explicitly recognizes biodegradable mulches within Operational Programs implemented by Producer Organizations. The decree specifies that *"soil biodegradable mulches shall be certified according to UNE-EN 17033:2018"* and includes the *"use of plastic and biodegradable plastic for mulching"* among eligible expenditures. This represents a concrete example of how CAP instruments can facilitate the uptake of biodegradable solutions as part of environmental and climate-related interventions in horticultural systems.

Complementing commercial experience, several European research initiatives have investigated the environmental performance of biodegradable mulch films. Several European project (since 2020 with “Bioplastics”), together with numerous field studies, have evaluated biodegradation behaviour under different climatic conditions, agronomic efficiency, soil impacts, and ecotoxicological aspects. These studies generally conclude that certified EN 17033 materials can substantially reduce the accumulation of persistent plastic residues in agricultural soils when used

appropriately and under conditions where complete retrieval of conventional films is not realistically achievable (Mazzon et al., 2026).

Overall, the combination of commercial implementation, CAP-based financial incentives, harmonized certification standards (EN 17033), and continued research and innovation provide a strong basis for considering certified biodegradable mulch films as a Best Available Technique (BAT) in selected agricultural applications characterized by low retrieval rates of conventional plastics and elevated risks of microplastic generation. Biodegradable mulch films since 2024 entered in the FPR as soil amendments with defined biodegradability requirements (*Commission Delegated Regulation (EU) 2024/2787 of 23 July 2024 amending Regulation (EU) 2019/1009 of the European Parliament and of the Council as regards the inclusion of mulch films in Component Material Category 9*, 2024)

B. International - FAO recommendations on biodegradable agricultural plastics

The FAO Voluntary Code of Conduct recognizes certified biodegradable agricultural plastics as a useful complementary solution for applications where retrieval is impractical, environmental leakage risks are high, contamination limits recycling feasibility (*A Provisional Voluntary Code of Conduct on the Sustainable Use and Management of Plastics in Agriculture*, 2025).

The guidance emphasizes that biodegradable mulch films should comply with recognized standards, demonstrate real soil biodegradation, and be integrated within broader sustainable plastic management strategies.

The FAO identifies certified biodegradable mulches as a promising tool for reducing long-term agricultural plastic pollution and associated microplastic accumulation (FAO, 2021).

7.6. BAT 6 – Promote certified biodegradable coating for fertilizers in accordance with FPR specifics

PRIMARY TARGET: fertilizer manufacturers, agricultural operators, distributors, policy makers, agricultural advisors.

DESCRIPTION: Preference should be given to biodegradable, and non-persistent coating technologies for controlled-release and stabilized fertilizers in order to reduce the accumulation of persistent polymer residues and associated accumulation of MNPs in agricultural soils. Polymer-coated fertilizers are widely used to improve nutrient use efficiency, reduce nutrient losses, enable controlled nutrient release, improve crop productivity.

However, conventional non-biodegradable polymer coatings may persist in soils after nutrient release, contributing to long-term accumulation of plastic residues, fragmentation into secondary microplastics, diffuse soil contamination, with potential impacts on soil ecosystems.

The use of soil-biodegradable polymers as coating has the aim to reduce persistent plastic inputs to agricultural soils, support transition toward safer fertilizer technologies, minimize secondary microplastic generation, improve environmental sustainability of fertilization systems, and promote circular and bio-based innovation.

This approach is aligned with the main regulatory frameworks on soil, circular economy and FAO recommendation to reduce agricultural plastic pollution. Recent FPR EU delegated act introduced biodegradability criteria for polymer coating

Recent EU delegated regulations introduced biodegradability criteria for coating agents and water retention polymerspolymer coatings used in fertilizing products (*Commission Delegated Regulation (EU) 2024/2770 of 15 July 2024 amending Regulation (EU) 2019/1009 of the European Parliament and of the Council as regards biodegradability criteria for coating agents and water retention polymers*, 2024).

ENABLING FACTORS: Implementation of BAT 6 can be facilitated by availability of certified biodegradable fertilizer coatings, innovation in bio-based polymer technologies, farmer awareness regarding environmental impacts of persistent coatings, research and development programs, incentives for sustainable fertilizer products.

TECHNICAL CONSIDERATIONS: BAT 6 should prioritize biodegradable polymer coatings compliant with EU FPR biodegradability requirements with and bio-based coating materials, optimization of polymers for application (coating thickness optimization), maintain agronomic efficiency, verify alternative coating materials, release efficiency, compatibility with precision agriculture systems.

RELEVANCE FOR MNP REDUCTION: BAT 6 directly contributes to reduction of persistent polymer accumulation in soils, and lower generation of secondary microplastics, reduced long-term agricultural soil contamination, lower diffuse plastic inputs from fertilization practices, improved sustainability of controlled-release fertilizers, promotion of circular and bio-based agricultural inputs.

Since fertilizer coatings are intentionally applied directly to soils, replacing persistent polymers with biodegradable alternatives may significantly reduce cumulative MNP accumulation over time.

The transition toward biodegradable fertilizer coatings is therefore considered an important upstream prevention measure for agricultural microplastic pollution.

EXAMPLES OF AVAILABLE BEST PRACTICES IN EUROPE

A. EU - biodegradability criteria for fertilizer polymers in FPR

The European Union introduced biodegradability criteria for polymer-containing EU fertilizing products under delegated regulations linked to the FPR (*Commission Delegated Regulation (EU) 2024/2770 of 15 July 2024 amending Regulation (EU) 2019/1009 of the European Parliament and of the Council as regards biodegradability criteria for coating agents and water retention polymers*, 2024)

The legislation establishes requirements for biodegradation performance, environmental safety, reduction of persistent polymer residues and conformity assessment procedures.

The regulatory framework encourages the transition toward biodegradable coatings and non-persistent stabilization technologies. As well it is important to secure harmless degradation products, using soil-life harmless additives. Important to integrate these aspects in the best practices, since plastics and additives might interact with soil stressors such as pesticides and veterinary medicines, which might interfere in the degradation processes. And might impact the terrestrial food chain.

CALL FOR INNOVATION: Technical solutions compliant with the requirements of the Fertilizing Products Regulation (FPR) with regard to coating agents are needed to mitigate the risk of microplastic (MiP) dispersion in soil. In particular, the development and use of biodegradable or natural polymer-based coating materials should be prioritized, as they can ensure the controlled release of nutrients while minimizing environmental persistence.

Such solutions should guarantee adequate agronomic performance, including coating stability during storage and application, while also meeting regulatory criteria for biodegradability, ecotoxicity, and soil safety. Furthermore, innovative coating technologies can contribute to reducing the accumulation of persistent MiP in agricultural soils, aligning product performance with environmental protection goals.

7.7. BAT 7 – Compostable accessoires for horticulture

PRIMARY TARGET: horticultural producers, greenhouse operators, agricultural cooperatives, composting operators, manufacturers of agricultural accessories.

DESCRIPTION: Compostable horticultural accessories such as clips, twines, ties, hooks, plant support materials, and fastening systems may represent a BAT for reducing plastic contamination in agricultural organic waste streams and facilitate joint treatment with plant residues while limiting the generation of persistent MNPs and improving the circularity and recovery of organic carbon (compost) in horticultural systems. Conventional plastic accessories used in horticulture and greenhouse systems are often difficult to separate from plant residues, contaminated with organic matter, unsuitable for effective recycling, and prone to fragmentation during collection and handling.

When mixed with green waste and crop residues, conventional accessories can contaminate composting streams, generate secondary microplastics, reduce compost quality, increase waste sorting requirements, contribute to environmental leakage. The use of compostable accessories while improving a sustainable and circular EoL of green waste supports high quality compost production (minimizing the plastic pollutants) and reduce labour-intensive plastic waste separation operations.

The approach is increasingly promoted within circular horticulture and greenhouse systems in several European countries and is consistent with the EU Circular Economy Action Plan ("Circular economy action plan - European Commission," n.d.), the EU Bioeconomy Strategy , the FAO Voluntary Code of Conduct for the Sustainable Use and Management of Plastics in Agriculture (*A Provisional Voluntary Code of Conduct on the Sustainable Use and Management of Plastics in Agriculture*, 2025) and the European circular horticulture initiatives.

ENABLING FACTORS: Implementation of BAT 7 can be facilitated by availability of certified compostable horticultural accessories, harmonized compostability standards, development of industrial composting infrastructure (closed to the greenhouse areas), farmer and greenhouse operator training, circular greenhouse horticulture initiatives, public procurement criteria favoring compostable products, certification and labelling schemes, innovation in bio-based materials, collaboration between horticultural producers and composting operators and increased market availability of durable compostable products.

The FAO guidance recognizes compostable agricultural accessories as a promising complementary solution for applications where separation and recycling are difficult (FAO, 2021).

TECHNICAL CONSIDERATIONS: BAT 7 should prioritize compostable accessories in applications where separation from plant residues is impractical, contamination prevents effective recycling, accessories are routinely mixed with organic waste streams, fragmentation risks are high, industrial composting systems are available. Preferred compostable accessories may include compostable clips, compostable twines, plant fastening systems, biodegradable support ties, compostable netting components, and compostable greenhouse accessories. These products should comply with recognized compostability standards, demonstrate biodegradation under composting conditions, avoid persistent residues, meet ecotoxicity requirements.

Appropriate standards may include standard EN 13432, industrial compostability certification systems, and relevant national certification schemes.

It will be important to consider various aspects for technical implementation, such as compatibility with crop management practices, durability during cultivation, composting process conditions, separation requirements for non-compostable components and traceability and labelling systems.

Joint treatment of compostable accessories with plant residues may result in reducing sorting operations, lowering contamination risks, improving composting efficiency, and reducing environmental leakage of small plastic items.

However, compostable accessories should be properly managed within suitable organic waste treatment systems and should not encourage littering or uncontrolled disposal.

RELEVANCE FOR MNP REDUCTION : BAT 7 directly contributes to reduction of persistent plastic residues in composting systems, lower contamination of organic amendments (e.g. : compost, digestate), reduced fragmentation of horticultural plastics, prevention of secondary microplastic generation, improved quality of compost and digestate, lower environmental leakage from mixed waste streams and improved circularity of horticultural waste management.

Replacing small conventional plastic accessories with certified compostable alternatives may significantly reduce diffuse sources of microplastic contamination, particularly in intensive greenhouse and horticultural systems.

This BAT is particularly relevant because clips, twines, and fastening systems are often difficult to recover separately and may otherwise persist in organic waste streams and agricultural soils (FAO, 2021).

EXAMPLES OF AVAILABLE BEST PRACTICES IN EUROPE

A. Netherlands - **Circular greenhouse horticulture systems (**Circulaire Glastuinbouw" approach)

Dutch greenhouse horticulture increasingly promotes the use of compostable clips, compostable twines, biodegradable fastening systems, compostable cultivation accessories (Malinconico, 2017).

These systems support joint processing of crop residues and accessories, reduction of sorting operations, lower contamination of organic waste streams, and improved circular waste management.

The "Circulaire Glastuinbouw" approach promotes reduction of disposable plastics and improved material circularity within greenhouse production systems ("Pathways towards circular plastics in Europe — good practice examples from countries, business and citizens," 2023).

Within the Dutch CAP Strategic Plan implementation (SIG&F – Sectoral Intervention for Fruit and Vegetables), producer organisations may include investments aimed at improving environmental performance and reducing plastic use in horticultural production systems. Although compostable clips and twines are not explicitly referenced in RVO guidance, they can be considered eligible as part of environmental and climate-related actions under Regulation (EU) 2021/2115 sectoral interventions for fruit and vegetables (Ministerie van Landbouw, 2022).

B. Spain - Compostable twines and clips for greenhouse cultivations in Almeria

Several horticultural producers in Italy and Spain increasingly use compostable tomato twines and clips in greenhouse cultivation systems.

These applications help to reduce contamination of plant residues, simplify post-harvest waste management, avoid separation of small plastic components, reduce risks of fragmented plastic residues entering compost streams.

The approach is particularly relevant in intensive tomato production where conventional plastic twines are difficult to fully recover (Novamont, 2025).

In a one-year experimental study conducted by Novamont and Bayer CropScience in greenhouses in Almería (Spain), compostable Mater-Bi clips were used for crop trellising and, at the end of the cultivation cycle, were collected together with plant residues and successfully processed in an industrial composting plant, producing high-quality compost without plastic contamination (Source: Novamont, 2025).

Compostable clips and wires are supported by CAP measurements aimed at promoting the adoption of innovative and more sustainable solutions for greenhouse cultivations (Ministerio de Agricultura, Pesca y Alimentación, 2022).

C. Belgium - Industrial composting integration projects

Several Belgian horticultural and composting initiatives tested integrated systems where compostable accessories, crop residues, and organic greenhouse waste are jointly processed through industrial composting systems.

The projects demonstrated reduced contamination of compost streams, lower sorting requirements, improved operational efficiency, lower residual plastic contamination (“ OVAM English website,” n.d.).

In Belgium a specific CAP measure was drafted to reduce waste and valorise by-products and waste streams, supporting the use of biodegradable and compostable materials in horticulture. Specific subsidies are reducing the gap costs between conventional and biodegradable/compostable materials: clips, ropes, brackets and clamps for nurseries are included in this program (“Agency for Agriculture and Fisheries,Landbouw en Zeevisserij,” n.d.).

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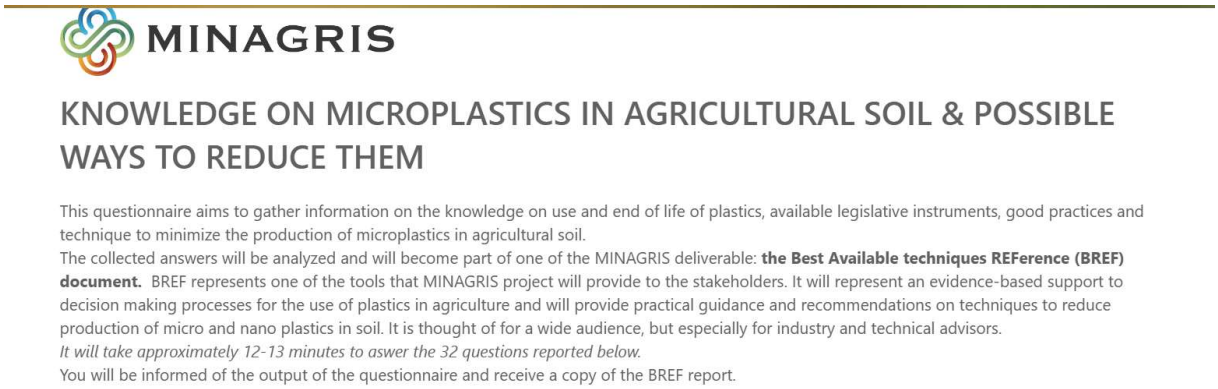
ANNEX 1 – STAKEHOLDER SURVEY – STRUCTURE AND QUESTIONS

A targeted questionnaire was administered to a selected group of over 30 stakeholders representative of the agricultural plastics value chain, including industry actors, sectoral associations, non-governmental organizations and institutional bodies. Stakeholders were identified and recruited based on their demonstrated expertise and prior involvement in initiatives, projects, or survey activities related to agricultural plastics, ensuring a well-informed respondent base. This selection approach was designed to enhance the quality, reliability and representativeness of the collected inputs across the sector.

The questionnaire aims to collect structured information on current knowledge and practices related to the use and end-of-life management of agricultural plastics, as well as on existing legislative frameworks, good practices and technical solutions for the prevention and reduction of microplastic generation in agricultural soils.

The questionnaire comprises 32 questions and requires approximately 12–13 minutes to complete. Participants will be duly informed of the main outcomes of the survey and will receive a copy of the final BREF document upon its completion.

The link to the questionnaire was sent to each stakeholder with a clear explanation on how to fill it in.


MINAGRIS

KNOWLEDGE ON MICROPLASTICS IN AGRICULTURAL SOIL & POSSIBLE WAYS TO REDUCE THEM

This questionnaire aims to gather information on the knowledge on use and end of life of plastics, available legislative instruments, good practices and technique to minimize the production of microplastics in agricultural soil.
The collected answers will be analyzed and will become part of one of the MINAGRIS deliverable: **the Best Available techniques REFerence (BREF) document.** BREF represents one of the tools that MINAGRIS project will provide to the stakeholders. It will represent an evidence-based support to decision making processes for the use of plastics in agriculture and will provide practical guidance and recommendations on techniques to reduce production of micro and nano plastics in soil. It is thought of for a wide audience, but especially for industry and technical advisors.
It will take approximately 12-13 minutes to aswer the 32 questions reported below.
You will be informed of the output of the questionnaire and receive a copy of the BREF report.

Figure 2. Opening page of the survey with explanation on aims and how to fill it in.

The survey is structured in 3 sections for a total of 33 questions, both open- and close-ended questions.

For the close-ended questions the scores ranging from 1 (poor) to 5 (very positive). For each question the average of the answers was calculated.

- **Part 1 – general data**: to collect general information on type of organization, where based (Europe, Member State) and main field of activity
- **Part 2 – State of art and knowledge gaps on microplastics and use of plastics in agriculture**, investigating the knowledge and data availability for plastics and MiP, and on legislative frameworks.
- **Part 3 – indicators for guidelines to reduce microplastics in soil**, investigating which can be considered feasible solutions to reduce the spreading of microplastics in the environment, with a particular focus on the plastic applications.

SECTION 1 – GENERAL DATA

6 questions, open and close-ended to collect the main information on the stakeholder

Q1 - *Full name*

Q2 – *Job title*

Q5 – *Name of organization*

Q4 - Type *of Organization* – close-ended question

- ◯ National association
- ◯ Institution
- ◯ Advisor
- ◯ University/Research
- ◯ Industry
- ◯ International Association
- ◯ NGO
- ◯ Other

Q5 – *Which of the following activities your organization is engaged in?* Close-ended question: select among different options

- ☐ agriculture
- ☐ plastics for agricultural applications
- ☐ environment protection
- ☐ collecting scheme for agri-plastics
- ☐ soil protection
- ☐ research on soil
- ☐ research on plastic
- ☐ other

Q6 – *Which country you association operates from?*

Q7 – *E-mail address*

PART 2 – STATE OF ART AND KNOWLEDGE GAPS ON MP AND USE OF PLASTIC IN AGRICULTURE

Part 2 is structured into four sections, comprising a total of 15 questions. Closed-ended questions require respondents either to provide a numerical rating (on a scale from 1 to 5) or to select one or more predefined options.

Section 1 – Statistics and data availability

Q8 - *In your opinion to what extent do you agree that statistics on the use of agriplastics are easily available?*

Numerical rating from 1 (not at all) to 5 (fully agree)

Q9 - *To what extent do you agree that statistics on the end-of-life of agri-plastics are easily available?*

Numerical rating from 1 (completely disagree) to 5 (fully agree)

Q10 - *To what extent do you agree that statistics on the end-of-life of agri-plastics are easily available?*

Numerical rating from 1 (completely disagree) to 5 (fully agree)

Q11- *In your opinion is enough data available in relation to the mapping of microplastics in the EU soils?*

Numerical rating from 1 (not at all) to 5 (completely)

Q12- *To what extent do you think that implementing the collection of data on agri-plastics and microplastics monitoring could support in solving plastic/microplastics pollution in soil?*

Open-ended question: “Please share your thoughts in detail, including any benefits or concerns.”

Section 2

Q13 - *To what extent do you think that implementing the collection of data on agri-plastics and microplastics monitoring could support in solving plastic/microplastics pollution in soil?*

Numerical rating from 1 (not at all) to 5 (completely)

Q14 - *In your view, what are the main sources of microplastics in agricultural soils?*

Numerical rating from 1 (not at all) to 5 (completely)

Q15 - *Which of the following parts of the agri-plastics value chain could contribute most to tackling contamination of microplastics in agricultural?*

Selection from predefined options – Chose one or more answers

- [ ] Design
- [ ] Production
- [ ] Transport
- [ ] Distribution
- [ ] Use
- [ ] End of life

Section 3 – Agri-plastics : end-of-life

The main end-of-life options for agri-plastics include collection, recycling, incineration and landfill

Q16 - *To what extent do you think that agri-plastics are currently properly managed at the end-of-life (collection and recycling) in the EU?*

Numerical rating from 1 (not at all) to 5 (completely)

Q17 - *What are the main challenges facing the end-of-life management for agri-plastic waste?*

Open-ended question.

Q18 - *How expensive is it to manage agri-plastic waste in the area where you operate?*

It would be advisable (if known) to report the cost for managing the agri-plastics' end of life in the area where operating

Open-ended question.

Q19 - *In your opinion, which agri-plastic products are the most difficult to manage when they reach the end-of-life?*

Please explain your answer in detail. E.g.: list types of agri-plastics in categories such as mulch films, greenhouse films, nets, irrigation tubes, etc.

Open-ended question.

Q20 - *How do you think the end-of-life processes for these products could be improved?*

Open-ended question.

Section 4 - State of the art on standards, legislation & guidelines to reduce microplastics

Q21 - *At which of the following scales are you aware of standard, legislation, and guidelines aiming to reduce microplastics in agricultural soils?*

Close-ended question: options to choose from.

- [ ] Local scale (e.g.: region)
- [ ] National scale
- [ ] European scale
- [ ] I am not aware

Q22 - *Please share examples of standards, legislation or guidelines for reducing microplastics in the environment, and ideally, in agricultural soil?*

Open-ended question.

Q23 - *To what extent do you think that the existing legislation/standard framework is efficient enough?*

Numerical rating from 1 (not at all) to 5 (completely)

Section 5 – Reduction of agri-plastics and replacing with alternative materials

Q24 - *Could you suggest three ways for reducing the presence of microplastics in soil?*

Open-ended question.

Q25 - T*o what extent could the implementation of non-plastic alternatives in agriculture offer an effective way to reduce the potential of microplastic contamination?*

Numerical rating from 1 (not at all) to 5 (completely)

Q26 - *Are there any particular applications of agri-plastics that you feel could be switched to non-plastic alternatives with relative ease?*

Please report maximum 3 alternatives.

Open-ended question.

Q27 - *To what extent do you agree that biodegradable and compostable applications could be considered part of the solution?*

Numerical rating from 1 (strongly disagree) to 5 (strongly agree).

Q28 - *Please explain the reasons behind your evaluation in question 27.*

Open-ended question.

Q29 - *To what extent do you agree that a reduction in use of plastics in agriculture could help to reduce the accumulation of microplastics in soil?*

Numerical rating from 1 (strongly disagree) to 5 (strongly agree).

Q30 - *Please explain the reasons behind your evaluation in question 27.*

Open-ended question.

Section 6 - Political instruments for reducing microplastics in agriculture

Q31 - *In your opinion, to what extent are the existing political instruments for managing end-of-life agri-plastics at EU and Member State level sufficient to guarantee a clean environment?*

Numerical rating from 1 (very insufficient) to 5 (fully sufficient).

Q32 - *In your opinion, to what extent are the existing political instruments for managing end-of-life your opinion, which of the following factors shape the success or failure of policy instruments in your country/area?*

Close-ended question: options to choose from.

- [ ] Time needed until positive changes can be observed
- [ ] Cost adoption
- [ ] Market pressure favours short-time priorities over long-time investments
- [ ] Weak monitoring and enforcement
- [ ] Strong monitoring and enforcement
- [ ] Knowledge and efficient dissemination
- [ ] Reluctance to change due to perceived peer pressure
- [ ] Biased information available

Q33 - *Would you be willing be willing to take part in a short interview to share with us further details?*

Close-ended question: Yes/No