EIP-AGRI Focus Group
Reducing the plastic footprint of agriculture

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1. Executive summary

This report presents the findings of the EIP-AGRI Focus Group on **"Reducing the plastic footprint of agriculture"**. Plastics can be found in each step of crop production, from containers for fertilisers to mulch covering the soil, the pipes irrigating the fields, and the packaging around the final products. Two aspects can define the plastic footprint of agriculture, the use of renewable resources, and the contamination of the environment with plastic debris. On the one hand, the collection of plastic waste in farms needs to be organised at a higher scale, with the collaboration of all stakeholders. Recycling agriplastics is a challenge because of the soil, moisture, plant debris and other materials that are collected along with the plastics. On the other hand, weathering and mechanical constraints can create plastic debris, which can enter the environment. A high plastic content has been identified in many fields, but the long-term effects of plastic contamination in the terrestrial environment remain uncertain. Plastic debris and, to a greater extent, microplastics (particles smaller than 5 mm) can be transported by the wind and by run-off water, and can be ingested by organisms. Based on these prerequisites, the Focus Group was established to answer the question: **How to reduce the plastic footprint in agriculture?** The group identified the state of the art of the current plastic uses in agriculture and the associated issues. The group discussed existing solutions to reduce the use of plastic, avoid debris with biodegradable plastics, limit the contamination from microplastics, collect waste in an efficient way, and recycle the plastics. Finally, the group identified knowledge gaps and innovation needs to fully tackle the plastic footprint in agriculture. The implementation of plastic waste collection schemes and the improvement of biodegradable plastics are two important levers.

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2. Introduction

Plastic is a relatively cheap, light and resistant material that can easily be implemented in a standardised manner and provides many benefits to agriculture. For example, plastics for greenhouses enable farmers to grow vegetables in a more favourable and controlled environment, while plastic as mulching film can reduce the need for water and herbicides (Espí et al. 2006). However, plastic use comes with two major issues. First, plastic production mainly relies on petrochemicals from petroleum and natural gas, which are not sustainable resources. Therefore, plastic use leads to resource management issues. For instance, the use of plastic in agriculture comes with specific management issues because the plastic comes into contact with water, soil and plants that leave residues (soilage). This make it more difficult to collect and recycle the plastic. Secondly, agricultural plastics are more likely than other plastics to be exposed to weathering in the fields, generating debris that accumulates in the environment in the absence of a proper collection system (Gionfra 2018). Additionally, the use of biofertilisers (e.g. compost and sewage sludge) contaminated by microplastics (particles <5 mm) is an important source of plastic contamination (Corradini et al. 2019). The accumulation of plastic debris in agricultural land raises concerns for soil health. For example, plastic debris in high concentrations reduces crop growth (Gao et al. 2019). Moreover, micro and macroplastics in a terrestrial environment can be transported by water run-off and wind to rivers and seas, where they threaten aquatic ecosystems. More specifically, plastic debris can be ingested by organisms, from plankton to mammals, causing digestive problems (Galafassi et al. 2019). Different strategies can be applied to reduce the plastic footprint in agriculture. This report summarises the discussions of a Focus Group of 20 experts about practical experiences to reduce the negative effects of plastic use in agriculture.

The overarching question of the Focus Group was: **How to reduce the plastic footprint in agriculture?**
The main question was addressed through a collection of specific tasks:

- Identification of the main use and properties of plastics in farming activities, and their advantages or threats for the sustainability of agricultural production
- Identification of the indirect sources of plastic contamination such as the use of contaminated biofertilisers or waste water
- Review of existing knowledge about the impact of plastic on the agricultural environment
- Discussion of the existing practices as well as limitations for the reduction of plastic use, its recycling and its degradability in the environment
- Exploration of opportunities and needs for innovations to reduce/replace the use of plastics while maintaining the economic and environmental performance of the farm
- Presentation of the existing monitoring methods and suggestion for ideas for improvement in this area

The working process of the Focus Group

The Focus Group (FG) is a temporary group of 20 selected experts coming from different professional backgrounds (list in **Annex 1A**). The group met twice in an online meeting, first on 18 to 20 May 2020 and then on 27 to 29 October 2020. The experts were first provided with a starting paper prepared by the Coordinating Expert, to establish a common understanding of the plastic use in agriculture, and to present some preliminary issues and already available solutions (**starting paper**). Prior to the meeting, the experts were also asked to fill in a survey. This featured a selection of questions on main concerns about plastic use in agriculture, and on the best practices to deal with plastic waste and contamination. The results of the survey are presented throughout the report.

The objectives of the first online meeting were to reach a common understanding and organise work in relation to the Focus Group's tasks. The experts discussed the facts presented in the starting paper, and five presentations from practice were made by FG members. Further discussions focused on challenges and barriers for reducing the plastic footprint, and possible solutions. Finally, experts were asked to provide ideas that they would like to develop in Minipapers (MPs) to be shared with farmers and stakeholders. The ideas were clustered in 5 topics (Figure 1) and experts could choose to which topic they wanted to contribute. In the following days other online meetings were organised to identify an outline for each MP. Find the full list of minipapers in **Annex 1B**.

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The objectives of the second online meeting in October were to finalise the MPs and to identify the research and innovation needs. The first day was dedicated to sharing highlights in the field of agriplastics. All experts got to share their work, and the concept of Operational Groups (OG) was introduced with the example of the Operational Group GO-ACBD, coordinated by expert Abelardo Hernández. On the second day, the experts presented the state of the MPs and discussed the points that had to be improved. The last day was dedicated to the future of agriplastics. The experts discussed the research gaps to be closed in priority, the need for innovation, and ideas for future Operational Groups. During the first two days the group welcomed Richard Thompson, who presented the FAO's initiative on agricultural plastics and sustainability and participated in the discussions.

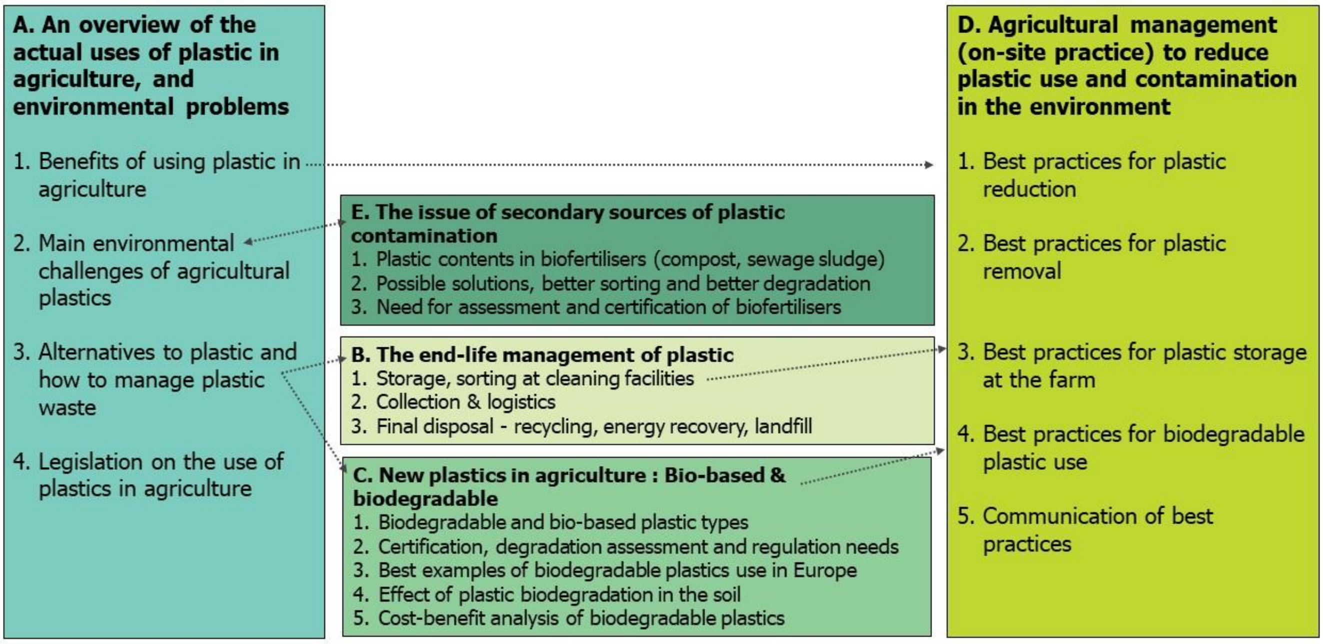

Figure 1: Presentation of five Minipapers and the links between them

3. Current situation, barriers and opportunities for reducing the plastic footprint of agriculture

3.1 Plastic in existing agricultural production systems

Current situation of plastic use

Plastics provide many services in modern agriculture (for more information about plastics, please see the starting paper). In agriculture, plastics are mostly used in the form of film, which constitutes a light, resistant, elastic, cheap and waterproof barrier (Figure 2). Plastic mulch, greenhouse cover, low tunnels and bale wrapping for silage preparation are the three main agricultural practices that use plastic films (Box 1). Plastics provide other services, namely as: crop protective nets; irrigation pipes/tapes; ropes and twines, crates and containers for farming products; coating for some controlled-release fertilisers. An estimation of the different uses of plastic in the EU in 2019 is presented in Figure 3.

Figure 2: Examples of plastic films used in agriculture: Lettuce being wrapped in plastic in a harvesting mobile station (left – copyright www.hortidaily.com), bale being wrapped in plastic for silage preparation (right – copyright www.farm-equipment.com)

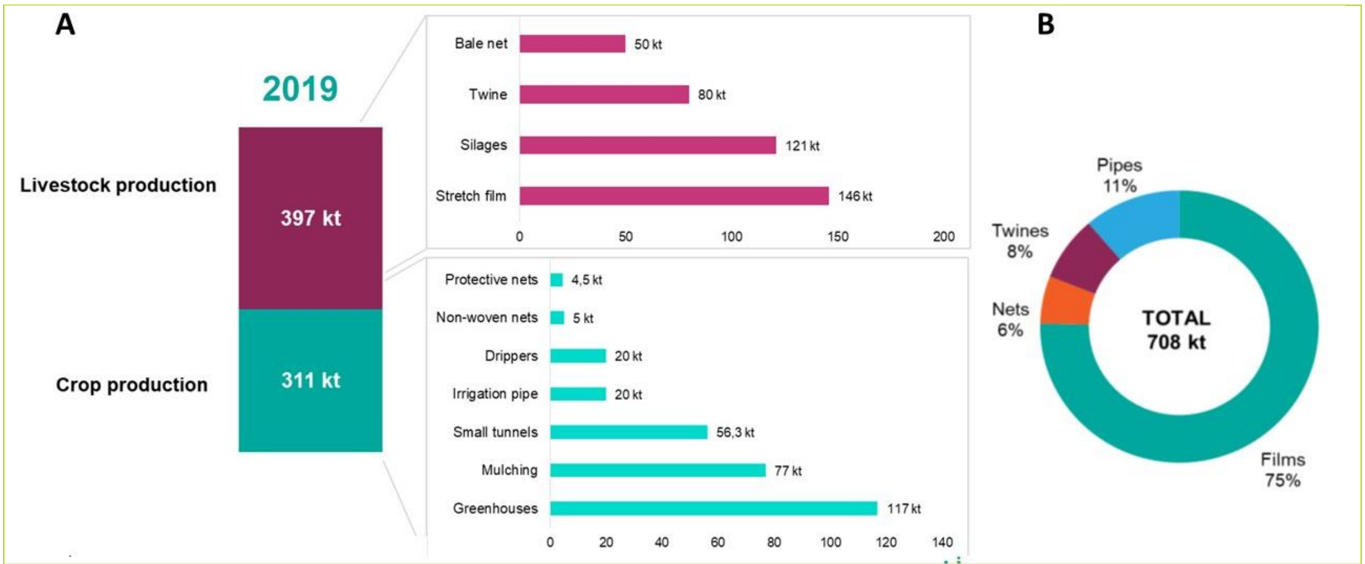

Figure 3: Estimation of the different uses of plastic in agriculture in the EU in 2019 for livestock and crop production (A) and the distribution of different plastic uses (B) (Eunomia, 2020 with data from APE Europe). Plastic packaging for agricultural products is not included in the figures and represents about 1000 kt in the EU in 2019.

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Box 1: The use of plastic film for mulching, an emblematic example of the agricultural use of plastic

Plastic mulch is a major issue in the use of plastic in agriculture because it is widely applied and comes directly into contact with the soil. This is why it has a strong potential to enter the environment (Steinmetz et al 2016). Plastic mulch is generally used for one or all of the following three objectives:

- **Increasing soil temperature**

Plastic mulch was first noted for its ability to increase soil temperature in the 1950s. Higher soil temperatures increase nutrient availability, enhance nutrient uptake by roots, increase the number and activity of soil microorganisms, speed up plant germination and growth, and can help to control pathogens (e.g. *Tuta absoluta* in tomato plants), leading to higher and earlier yields. Therefore, plastic mulch may reduce the need for fertilisation. The increase of the temperature mostly depends on the colour of the plastic. Black is the predominant mulch colour since it can both absorb and re-emit solar radiation as heat. By contrast, transparent plastic films are poor absorbers of solar radiation but they transmit 85% to 95% of radiation to the soil. This greenhouse effect makes transparent films profitable in colder regions, or in hotter regions for soil solarisation. Soil solarisation is a soil sterilisation method to eradicate soil-borne pathogens and devitalise weed growth by reaching a very high temperature (increase of ~15ºC of the soil temperature at 25 cm) (Tamietti and Valentino 2006), depending on the location and external conditions. At night, the plastic mulch prevents heat loss by limiting soil radiation.

- **Increasing water use efficiency**

The water use efficiency (WUE) is estimated by dividing the yield per ha by the total amount of water applied. Plastic mulch is a barrier that prevents water evaporation from the soil and therefore increases water availability for plants (Deng et al. 2006). Plastic mulch can also increase rainwater harvesting when associated to ridge-furrow tillage, the ridge being mulched by plastic and plants growing in the furrows (Figure 4) (Yang et al. 2020). An analysis of 266 studies showed that plastic mulching significantly increased crop yield by 24% and WUE by 28% on average (Gao et al. 2019).

- **Decreasing weed growth**

Opaque (often black) plastic mulch avoids weed growth by preventing light to reach the soil (William James 1993). Plastic mulch can reduce weed emergence by 64% to 98% during the growth season, depending on the surface that is covered with plastic (Kasirajan and Ngouajio 2012). In this sense plastic mulch contributes to reducing the use of herbicides. With clear plastic mulch, a herbicide is needed to prevent weed growth beneath it.

Because of these benefits, plastic mulch is used under various climatic conditions, in open field and in greenhouses, for the production of different crops, and both in organic and conventional farming practices.

Plastic mulch is often partially buried in the soil to prevent it from being blown by the wind (Figure 4). However, weathering, the growth of plants, the use of machinery, and harvesting damage the plastic mulch, that tends to get fragmented (Figure 5). This fragmentation after the crop season makes the full removal of the plastic impossible. Debris is left in the soil if no meticulous collection techniques are used.

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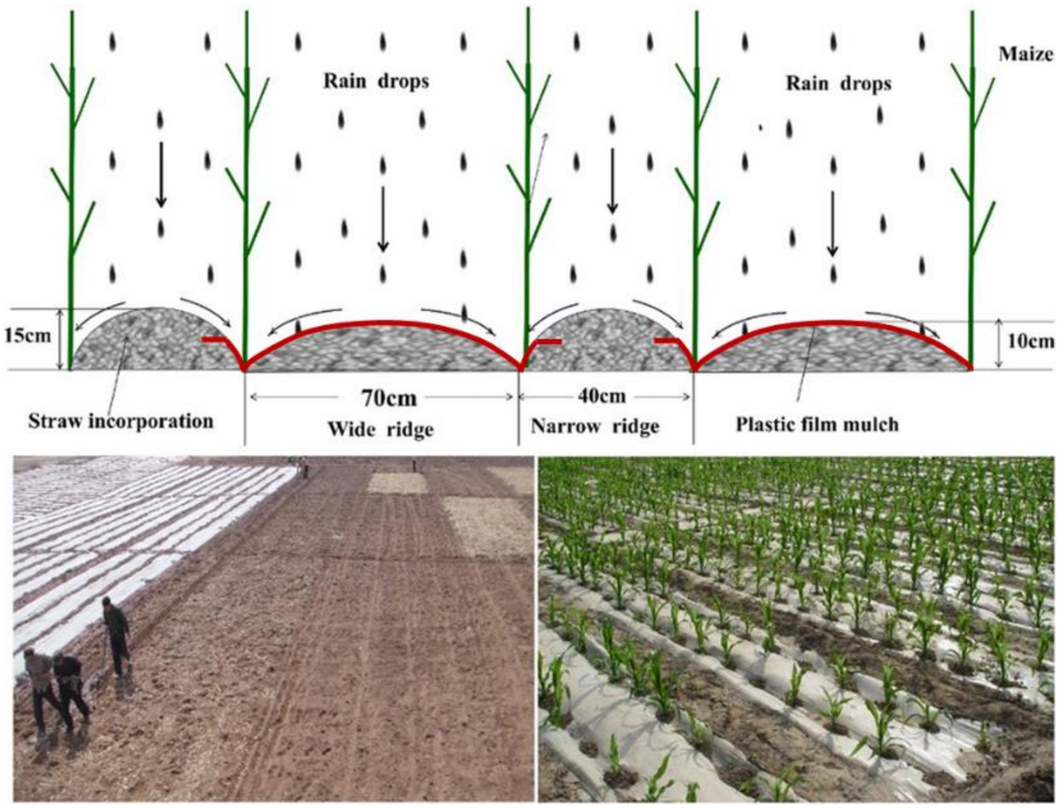

Figure 4: An example of the use of plastic mulch: Film-mulched ridge-furrow tillage combined with straw incorporation to increase water use efficiency and soil quality, experimental case for maize growing in the Semiarid Loess Plateau, China (Yang et al. 2020)

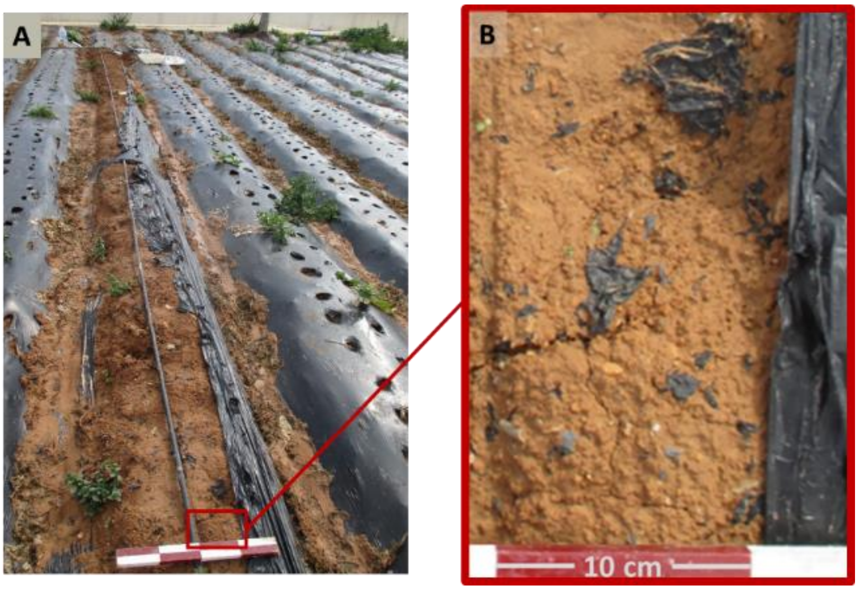

Figure 5: Low-density polyethylene plastic mulch after harvest of Kohlrabi in Southeast Spain. The sides of the mulch film are buried into the soil, making complete removal impossible and leading to debris accumulation over time.

Problems related to plastic use

In a preliminary survey, the experts of the FG were asked about their main concerns regarding plastic use in agriculture (Figure 6). They mostly expressed concerns about the additional waste management required for plastic. Most plastics have a short duration of use (e.g. one cropping season for plastic mulch, 3-5 years for greenhouse covers). Therefore, a lot of agricultural plastic waste has to be collected and processed every year.

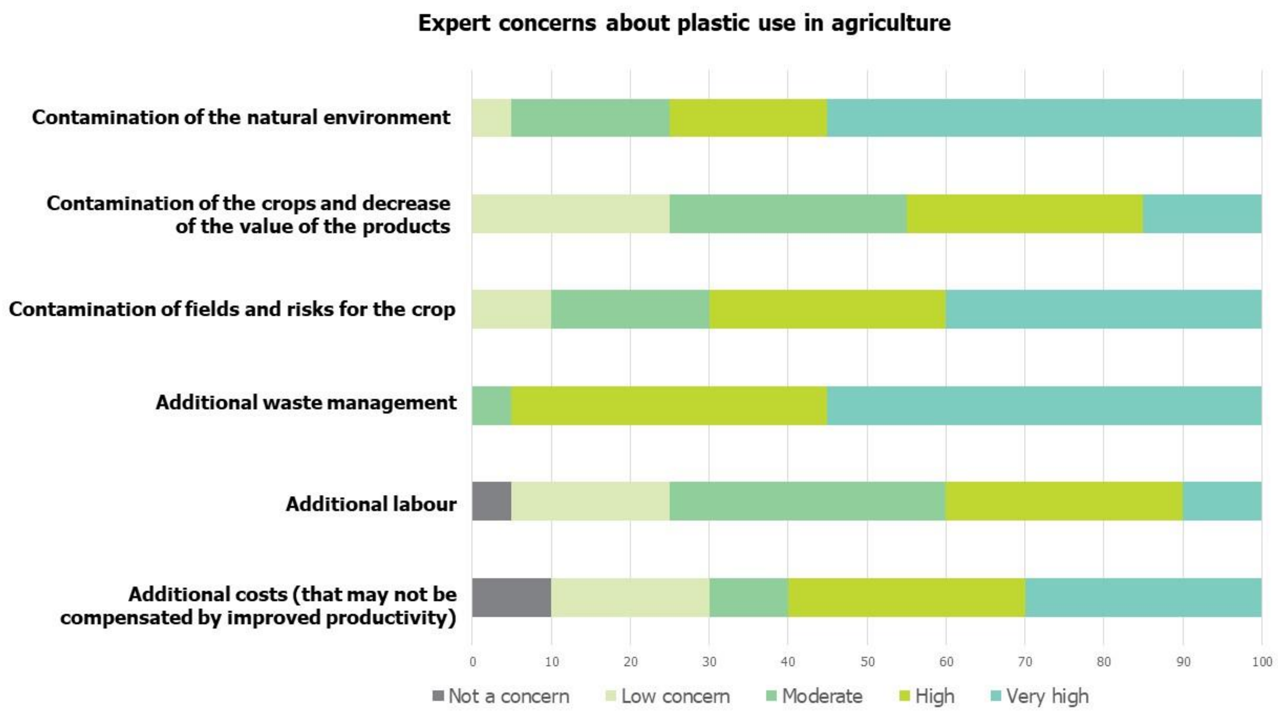

Figure 6: Results of the preliminary survey of the experts about the issues caused by plastic use in agriculture

The second most important issue raised by the experts was the potential contamination of the environment and the agricultural fields. When it is not collected properly, plastic waste can contaminate the environment. Big plastic debris can undergo degradation into microplastics. Plastic pieces and microplastics can easily be transported by the wind and by surface run-off (Figure 7), and accumulate in the environment (**Annex 5**).

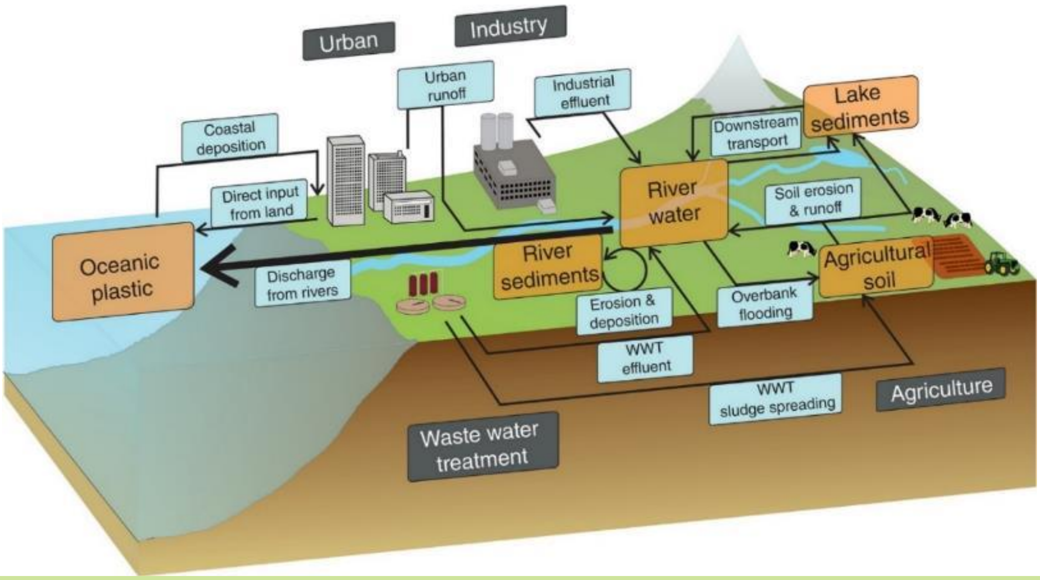

Figure 7: Conceptual model of plastic transport. Orange boxes represent sinks, blue boxes represent transport mechanisms, and arrows represent transport pathways. Atmospheric microplastics are not included within the model as they cannot be attributed to a specific compartment or route of transport (Horton and Dixon 2018)

Plastic debris can be harmful to fauna. Studies showed that many organisms do ingest plastics. For example, 1000 particles per kilogram of faeces were found in sheep herds in the South of Spain. They had been grazing in vegetable fields where plastic mulch had been used (Beriot et al. 2021). Moreover, microplastics that have been ingested by organisms can travel in the food chain. For example, microplastic concentrations increased from soil (0.87 ± 1.9 particles g^{-1}), to earthworm casts (14.8 ± 28.8 particles g^{-1}), to chicken faeces (129.8 ± 82.3 particles g^{-1}) in home gardens in Southeast Mexico (Huerta Lwanga et al. 2017). Adverse effects of animals ingesting microplastic include blockage of the intestinal tract, inhibition of gastric enzyme secretion, reduced feeding stimuli, decreased steroid hormone levels, delays in ovulation and even failure to reproduce (Li et al. 2016). Ecotoxicological effects at environmental concentrations are still uncertain (Chae and An 2018; Ng et al. 2018).

Plastic debris can also be detrimental to plants and crops (Bosker et al. 2019; Chae and An 2020; de Souza Machado et al. 2019; Jiang et al. 2019; Qi et al. 2018; van Weert et al. 2019). On a larger scale, Gao et al. showed a yield decrease with increasing amount of plastic residue, when the plastic was >240 kg/ha (~0.15 g/kg) in fields using plastic mulch in China (Figure 11, C) (Gao et al. 2019). Apart from risks for crop production, macroplastics may be a threat to the quality of the product. Indeed, in leaf vegetable agriculture, macroplastics may get stuck in the leaves. These products are less appealing to the consumer and need an extra cleaning step to remove all plastic debris.

Contamination results in exposure to humans. Microplastics have been reported in many food items (**Annex 5**). The estimated intake of microplastics is 39,000–52,000 particles $person^{-1}$ $year^{-1}$ (Cox et al. 2019). Microplastics may cause inflammatory lesions and induce an immune response (Figure 8).

The consequences of plastic contamination are further described in **MP A**.

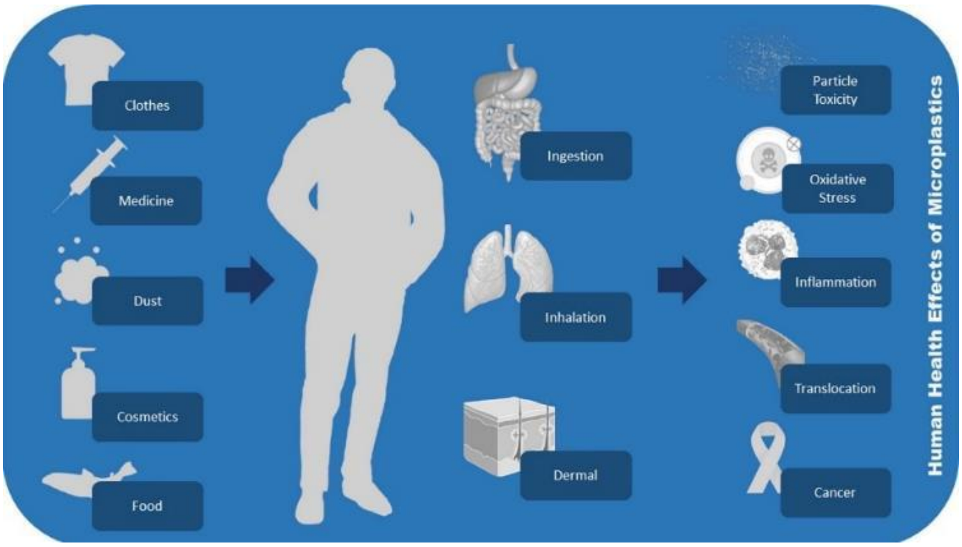

Figure 8: Sources, pathways and possible effects of microplastics on human health (Prata et al. 2020)

Barriers to the reduction of plastic use

The unique qualities of plastic (e.g. light, resistant, cheap and waterproof) make it difficult to replace in agricultural practices while maintaining the current practices, yields and production cost. Using less plastic requires changing the current agricultural management, which may be costly and may lead to a decrease of productivity. Therefore, maintaining high productivity may compete with the willingness to organise more sustainable management.

Opportunities to reduce the use of plastic in agriculture

New production systems (e.g. intercropping, agroforestry, cover crops) in some cases enable farmers to use less plastics while providing other services (better pest control, increased resilience to extreme climate events, weed management). Further explanations on these opportunities can be found in **MP D**.

3.2 Types of plastic used in agriculture

Current types of plastic used in agriculture

Plastics are manufactured from one or from a blend of polymers. These polymers are formed by chains of carbon atoms that can have different origins. Most plastic polymers are petroleum-based, meaning that they are derived from petroleum. Agricultural plastic accounts for less than 0.3% of the EU's petroleum consumption. In contrast, 5% of petroleum is used for all plastic production and ~85% is used for transport, electricity and heating in the EU. Alternatively, plastic polymers can be bio-based, meaning that they are produced from plant products such as vegetable fats and oils, corn starch, straw, woodchips or sawdust.

There are many different kinds of plastic polymers based on their chemical composition, regardless of their origin (petroleum-based or bio-based) (Picuno P., 2018). Different polymers have different properties (**Annex 2**). The two main polymers used in agriculture are polyethylene and polypropylene (Figure 9). Polyethylene (PE) is mainly used as low-density polyethylene (LDPE) for the production of plastic films (plastic mulch, greenhouse covers, tunnels, packaging). Polypropylene (PP) is harder and more heat-resistant than polyethylene, and it is used mostly in pipes and containers. Polypropylene is also used for woven plastic films. Both polyethylene and polypropylene are very resistant and are not biodegradable.

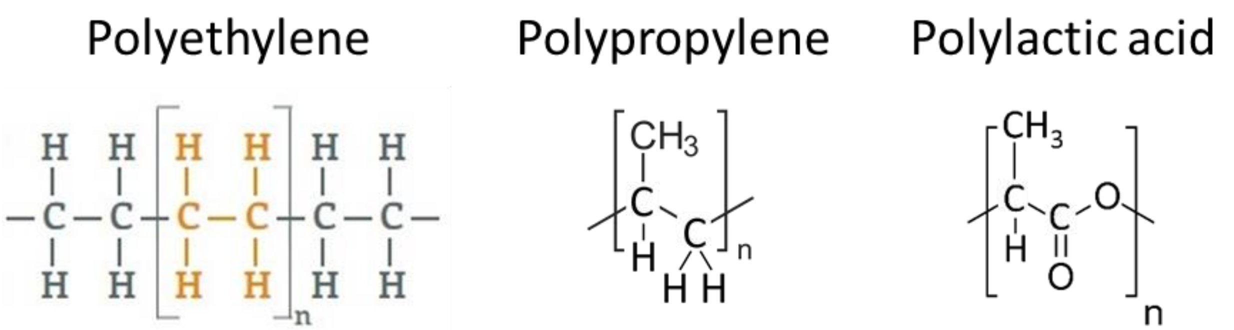

Figure 9: Chemical structure of common polymers used in agriculture, polyethylene (PE), polypropylene (PP) and polylactic acid (PLA)

Biodegradation of a polymer is a biological process leading to its complete or partial conversion to water, CO_2, methane, energy and new biomass by microorganisms (bacteria and fungi) (van Ginkel 2007). Biodegradation can be measured as a mass loss, a change of plastic properties or an increased emission of CO_2 (Lucas et al. 2008). The biodegradation process depends on time, on the abiotic and biotic conditions, and on the properties of the plastic (Sander 2019). The International Organization for Standardization (ISO) 17556, considers that biodegradable plastic should reach at least 90% biodegradation in the soil within two years (Carol et al. 2017). Different certifications for biodegradability exist according to specific conditions and biodegradation time. For example, some plastics require the controlled conditions, stirring and high temperature that are maintained in an industrial compost plant, in order to be degraded. They can be labelled "biodegradable in industrial compost plant" or "Ok compost industrial" also known as "compostable". Other plastics require the conditions of an individual composter and can be labelled "biodegradable in home compost" or "Ok home compost" also known as "home compostable". Similarly, plastic can be biodegradable in soil, in fresh water or in marine environments. For example, polylactic acid (PLA) undergoes significant biodegradation in industrial compost conditions but undergoes slow to no degradation in field conditions (**Annex 4**). Most biodegradable plastics are a blend of different polymers to combine the fast biodegradation of one polymer with the resistance of another. Biodegradable polymers can either be petroleum-based or bio-based (Figure 10). For example, less than 30% of the content of most biodegradable mulching films that are available in the market are bio-based.

In addition to plastic polymers, plastics also contain additives. These molecules are added to control the properties of the plastic, the elasticity, the colour, the mechanical strength or the degradability. For example, additives play a

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major role in the degradation of pro-oxidant additive containing (PAC) plastics. PAC plastics are polymers, mainly LDPE, which contain a pro-oxidant additive to enhance oxidation and photo-degradation (Selke et al. 2015). In the presence of light and under aerobic conditions, PAC plastics quickly degrade into small pieces. PAC plastics are also commercialised as oxo-plastics, photodegradable plastics, oxo-bioplastics. PAC plastics are not biodegradable because their degradation relies mainly on abiotic processes.

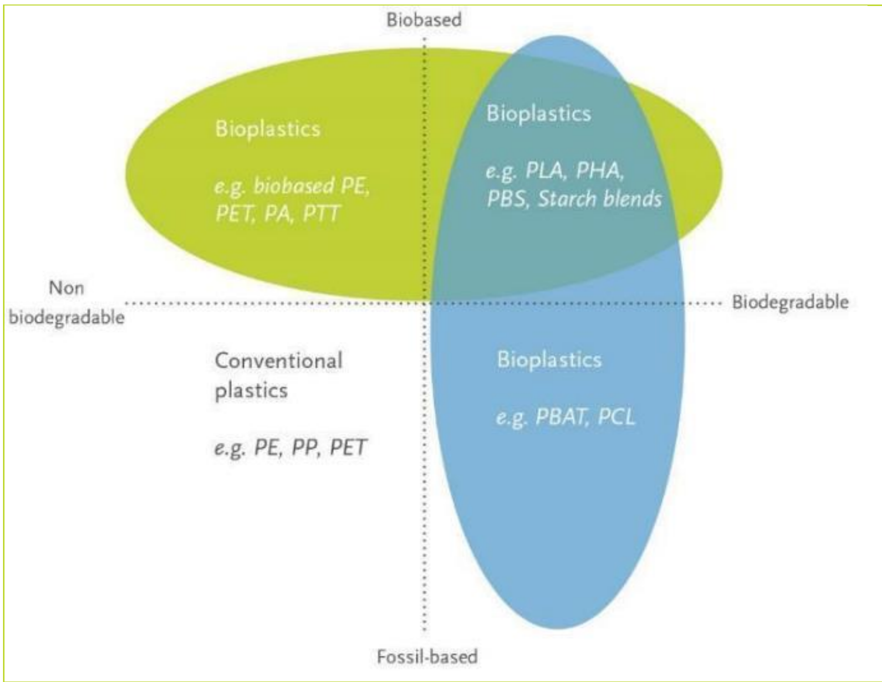

Figure 10: Some key plastics used in agriculture, characterised according to their source materials and biodegradability (European Bioplastics, 2018)

Problems posed by different polymers

Resistant plastic polymers, e.g. PP, LDPE, accumulate in the environment if not properly collected and stored. Moreover, the degradation in the environment of PAC plastics is mostly incomplete. When all additives are consumed and the abiotic conditions are not favourable, the degradation process stops (Selke et al. 2015). Biodegradable plastics are designed to degrade under specific conditions and a specific timeframe. These are not always matched in the field, potentially leading to degradation that is either too fast for the proper use of the plastic, or too slow, leading to an incomplete degradation and accumulation in soil. Moreover, biodegradable plastics in soil are a source of carbon and energy for some microorganisms. Therefore, it is expected that biodegradable plastic will modify the soil microbial community (Accinelli et al., 2020, Qi et al. 2018). It is unknown if this change will have an impact on beneficial or pathogenic microorganisms or if it will have no consequences for the plant growth. Finally, many plastic additives are suspected to be endocrine disruptors (Chen et al. 2013) (**Annex 3**). It means that they may interfere with animal hormones and therefore impact the entire organism (Hermabessiere et al. 2017).

Barriers for improving plastic polymers

Biodegradable and bio-based plastics are more expensive to produce than conventional plastics and tend to require more energy to produce. For example, bio-based plastics are generally made from crops, of which the production requires the use of lands and fossil fuel for agricultural activities. Moreover, new production methods of bio-based plastics and innovative blends for biodegradable plastics do not have the large production scale that conventional ones have. Additionally, the study of the toxicity of plastic additives is complicated, because plastic producers do not share the composition of the additives, due to industrial ecrecy (Ebere et al. 2020).

Opportunities for the development of new plastic polymers

Upscaling the production in response to an increase in demand may decrease the cost of new biodegradable and bio-based plastics. FG experts state that this has not been observed yet, after more than 20 years of development of biodegradable plastics. On the other hand, if the costs of the after-life processes are considered, biodegradable plastics can be ~10% cheaper than conventional plastics. Finally, bio-based plastic could be made from crop residues and organic by-products, and would therefore not need any additional crop production. More details about biodegradable plastics and their further development can be found in **MP C**.

3.3 Collection and recycling of plastic waste

Current situation of collection and recycling of plastic waste

Farmers have to manage the plastic waste that is produced at their farms. The on-farm burning or burial of plastic mulch is forbidden in most countries, so the plastic has to be collected and transported to waste treatment facilities. Some countries organise the collection and treatment of agricultural plastic waste with national or local schemes (see Box 2: agricultural plastic collection schemes). After collection, the plastic can be cleaned and processed to make new plastic products. Alternatively, plastic waste can be used to recover some energy, it can be burnt in an incineration plant to produce electricity or used to produce syngas and other energy carriers (Miskolczi et al. 2009).

Problems with the collection and recycling of plastic waste

The collection and storage of plastics after usage is an additional work for farmers. Plastic waste should be stored in a dry place, where it is protected from the wind to keep the plastic waste clean, and prevent it from being blown away (Figure 11). Removing plastic debris in the field is laborious. Improper collection and storage lead to contamination of the environment with plastic debris.

Figure 11: Example of common but not ideal storage of plastic waste on the farm

Box 2: Examples of existing plastic collection schemes

France - ADIVALOR

"ADIVALOR" is a recycling organisation in France. It is a non-profit company with different kinds of associates (cooperatives, retailers, manufacturers of fertilisers, of plastic films, etc.). It consists of a total of 300 organisations that pay a contribution to finance the system. Thus, it is not the users of ADIVALOR (mainly farmers) who pay directly, but the financing of the scheme is possible thanks to the contribution of all market players in the value chain. More than 1 000 organisations collect 66 000 tons: empty cans of pesticides, bags of seeds, big bags of fertiliser, plastic films from silage, protective nets.

Andalucía - CICLOAGRO / MAPLA

In Andalucía there was a scheme, called CICLOAGRO, to collect and recover the waste from agricultural plastic films (greenhouses, tunnels and mulches). However, the scheme ended its activities in 2018 and there have been no plastic waste or recovery actions since. Recently, a new association named MAPLA has been created at national level, taking over CICLOAGRO. Its main purpose is to organise and contribute to financing a new system model for managing non-packaging agricultural plastic waste.

Germany - RIGK

In 2013, the German industry association for plastic packaging, in partnership with waste disposal specialist RIGK, created a national recovery system for agricultural film. The scheme, called ERDE, started to collect a variety of film types in 2014. Its activities are funded by member companies, i.e. manufacturers and importers. ERDE's success is reliant on voluntary participation; currently there are 7 participating manufacturers and over 20 collection partners. Farmers are incentivised to return their used plastics to collection points by a bonus, which can be redeemed against a future purchase. According to RIGK, ERDE collected 5 412 tonnes of agricultural film in 2016, a 16.6% increase in comparison to 2015.

Sweden - SvepRetur

In 2002, SvepRetur organises the collection of plastic waste material from farmers. The collection is carried out by a subcontractor. SvepRetur collects environmental fees from the market, a levy that the product selling companies charge their customers (74€/T). The goal is to collect 70% of the sold plastics. Users deliver their used material to 340 collection points all over Sweden.

Ireland - IFFPG

In 1997, Ireland introduced legislation designed to assist and promote the recycling of agricultural plastics. Consequently, all producers are members of the IFFPG (Irish Farm Film Producers Group). IFFPG is a mandatory scheme. Producers must either participate or self-comply. The IFFPG is funded through a recycling levy charged to producers (75%) and a weight-based collection fee charged to farmers (25%). The IFFPG arranges the collection and recycling of farm plastics across Ireland, either through bookable farmyard collections or a number of local one-day bring-centres (it ran 237 such centres in 2016). The scheme is operating successfully. In 2016, the IFFPG collected 27 193 tonnes of farm plastics waste leading to 74% recycling of what producers placed on the market in the previous year. Of the plastics collected, over 60% was supplied to Irish recyclers.

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Barriers in the collection and recycling of plastic waste

Plastic waste management is an additional cost that has to be covered by the farmer, the plastic producer or by society. All existing schemes are financed through the cost internalisation within the Extended Producer Scheme. Therefore, the farmers are paying for the end-of-life management of the plastic they use, and the cost is transferred onto the price of the new product. Whether this system is ideal and who should be charged for collecting and recycling remain open questions, and financing may be the main challenge for constructing an efficient plastic ecosystem. For example, after a recycling company in Portugal went bankrupt, producers' associations were proposing a tax in order to encourage investments in the recycling of plastic mulches. Additionally, in many countries farmers lack support (financial and technical) to deal with plastic collection. For example, the FG experts pointed out that in Italy and Croatia there is still no effective plastic collection and the plastics are taken to landfills. Collection and recycling of plastic is difficult due to the lack of adequate facilities (e.g. Box 3).

Additionally, agricultural plastics may be contaminated with pesticides, covered with dirt, soil or stones, or mixed with plant residues, making a cleaning step necessary before further recycling. In general, the reuse of plastic with the steps of collection, cleaning, and recycling, is too expensive in comparison to the price of virgin plastic production, depending on the cost of the crude oil, from which plastics are produced.

Opportunities to manage the collection and recycling of plastic waste

Two approaches can be considered. On the one hand, plastic waste can be seen as a resource. Innovative processes can make new products out of plastic waste. For example, in Finland silage films (because these are clean enough) are recycled and made into new plastic products. **MP B** gives more insights in the different solutions for plastic collection and recycling. On the other hand, biodegradable plastics could replace plastics that are used in the field and could be left to degrade in the soil or composted. Therefore, there is a reduced need for collection and recycling biodegradable plastics. These two approaches work in parallel for different uses of plastic. Uses leading to high soilage (e.g. plastic mulching) are good candidates for biodegradable plastics while recycling can make clean plastic waste (e.g. greenhouse covers) more profitable.

Box 3: Agricultural waste in Poland

Plastics used at Polish farms have different sources and very few places where they can be recycled. Most of these plastics were previously exported to China. Due to demands for an additional plastic waste system, a new law was passed in Poland upgrading the requirements for plastic recycling facilities. Because of this, a lot of collecting facilities have closed. In some areas, local governments pay a company to harvest plastics. Farmers usually keep plastics at the farm for two or three years, and then sell them in bulk when the quantity is sufficient. However, in general, farmers do not know what to do with plastics. Plastic from balloting straw and hay is the biggest problem, followed by the one generated from fertilisers and plant protection containers.

A survey conducted by the company AgroWe to 370 farmers in Poland showed that soil pollution due to plastics is largely underestimated (compared to topics such as lack of water, for instance). This means that plastic is perceived as a problem only from an economical point of view. Therefore, an efficient economic ecosystem would reduce the problem because businesses would see plastic as an opportunity rather than a waste.

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3.4 Awareness and availability of information

Current awareness of the plastic footprint in agriculture

The concerns about plastic waste and plastic contamination in agriculture are rising, but they remain generally unknown for society and for agricultural stakeholders.
The FG experts pointed out that the primary concern of farmers is to produce profitable crops to run their farm. They have to deal with a fluctuating food market, new production techniques, changing policies and subsidies and a growing environmental concern in society. Plastic waste and plastic contamination form an additional issue faced by farmers, but in most cases this is far from being their primary concern.
Moreover, some information is not available for farmers or even for their agronomist consultants / extension services. For instance, the product information that is available to farmers who are using plastic, rarely states the composition of the plastic and it is sometimes misleading. Additionally, some information is not stated clearly. For example, some plastics can be sold as biodegradable without stating under which conditions the plastic would degrade.

Problems concerning the limited awareness and lack of information

Farmers have limited time and energy to invest in dealing with plastic waste and plastic contamination. This can lead to confustion and a lack of awareness. For example, some farmers may confuse bio-based plastic and biodegradable plastic, and the term "bioplastic" used by some industries is increasing the confusion.
Moreover, the lack of knowledge and information that is available may lead to farmers ploughing in plastics that are not biodegradable into the soil, which results in plastic contamination. As stated before, the biodegradation in soil depends on the abiotic and biotic soil conditions and on the properties of the plastic. Therefore, farmers may need to try different types of biodegradable plastics to find the one that will degrade in the desired period of time in their field conditions. However, in most cases the composition of the plastics is not available to farmers, making the comparison between products more difficult. Since the composition of plastics is not available, farmers and advisers cannot identify, predict or recommend specific blends that would decompose efficiently under their field conditions.
Finally, the FG experts considered a lack of communication between farmers, advisers, industries and researchers, as a reason why best practices for plastic use are not always known and used at farm level.

Barriers to improve awareness and make information available

The protection of different plastic types under intellectual property rights is a barrier for farmers, advisers and scientists to understand, predict and recommend specific plastic blends for an efficient degradation in a specific environment. Additionally, the lack of certification and clear communication is a barrier for the proper use of biodegradable plastic.

Opportunities for a better awareness and access to information

The growing concern for plastic pollution in aquatic environments (in oceans and rivers) may raise concerns and increase awareness about plastic contamination in agriculture as well.
Existing farmers' associations can help to share knowledge. Certifications (such as TUV-Austria) try to set clear conditions for the plastic degradation and therefore promote a better understanding and use of biodegradable plastics. In countries with collection schemes and national monitoring, the quantities of plastic used, collected and recycled in the collective scheme are made public. Finally, similar concepts and regulations about the communication and testing of active molecules and additives that are used in plant care products could be implemented for agriplastic, to help farmers choose the best products for their activities.

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4. Reducing the plastic footprint of agriculture: existing solutions and innovations needed

4.1 Reducing: use of local resources and new agricultural management types

The first step to reduce the consumption of plastic in agriculture and consequently reduce plastic waste and plastic contamination is to reduce the use of plastic. The possible alternatives to plastic use include:

- **Crop residues for mulching**
  Plant residues (straw, bark or ramial chipped wood) can be used to cover the soil and reduce water evaporation and weed growth. Even if the effects are often less strong than with plastic mulch, crop residues may be a recommendable alternative when they are abundantly and locally available.
- **Using cover crops to replace mulching**
  Growing cover crops can provide a solution to control weed growth and conserve soil moisture. Farmers need to choose the type of cover crop carefully, as shallow-rooted crops may decrease soil moisture in the topsoil.
- **Shifting from silage to hay for livestock feed**
  Livestock can be fed with hay instead of silage to avoid the use of plastic for bale wrapping and the need for managing plastic waste.

4.2 Reusing plastic

If the same agricultural practices are kept, the need for plastic in agriculture could be reduced by extending the duration of currently used plastics. For example, in case of plastic mulch some farmers apply a thicker version of normal low-density polyethylene and use it for several crops in a row. This is the case in Portugal where some farmers use one strong plastic for 8 years, with a double-tomato crop production per year. This is also commonly applied in asparagus cultivation (Box 5). In a similar way, stronger plastic films for greenhouse and tunnel covers would have a longer life span. However, it should be assessed that an extension of the lifespan is worth the use of stronger plastic films, because stronger often means that more resources are used and the waste is heavier.

4.3 Plastic removal methods and on-farm cleaning

An efficient removal and collection of plastics after their use is critical to avoid contamination of the environment and to enable their proper treatment (Picuno et al. 2020). It is particularly needed for plastic mulch because this is often partially buried and tends to be ripped off during removal. Proper techniques and innovative machinery can help to reach the full recovery of the plastic, and help to clean the plastic while it is collected. Experts pointed out that currently no techniques are available to remove microplastics, and that the use of extra machinery to collect plastics from the field may induce additional soil compaction (Box 4).

The experts shared already available instructions for cleaning agricultural plastic, that can be performed on the farm (e.g. http://svepretur.se/en/our-services/proceed-as-follows/):

1. **Sort the plastic;** agricultural plastic comes in different forms and each type must be sorted individually for it to be recycled.
2. **Handle and store the plastic** so that it stays as dry and clean as possible
3. **Clean the plastic** with water; a rotating tank can be used.
4. **Hand in plastic** for recycling at a collection point; plastic can be packed with a hydraulic press at the farm to make transportation easier.

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Box 4: Reusing and removing plastic from the field, the example of asparagus and tomato production in Navarra (Spain)

Navarra (Spain) has a big horticultural sector, using a lot of plastic mulch, and producing about 250 t/ year of plastic waste (68% coming from mulching).

A manual of good practices was developed to convince farmers of the benefits of collecting plastic waste and to raise awareness of the problem of plastics contamination such as: reducing soil quality and health, damaging machinery, and possible CAP sanctions. The manual describes good practices to reuse the plastic when possible.

For example, in case of tomato production, the plastic mulch is mechanically picked up during harvest. The plastic mulch cannot be reused by the farmer to re-plant tomatoes. But, with correct machinery (chise), there is no need to remove the plastics. For asparagus cultivation, the plants are covered with plastic throughout the growing season, but not at harvest. With the proper machinery, the plastic can be removed and stored before being applied again for the next season. White plastics and black plastics are used in different seasons depending on the desired growing process, and removing and storing the plastics allows the farmer to adapt the colour of the mulch without generating more waste.

When plastic has to be removed, there are several types of machinery that lift the plastic from the field, preventing tearing to maximise the recovery of plastic. This is very important, to make sure that plastic mulch removal does not leave debris in the soil and that irrigation belts can be reused. High quality plastics are needed, to allow the plastic to be removed and reused.

Finally, while increasing removal efficiency, reducing management costs is needed for a wide application of these techniques. The cost of machinery can be lowered when shared by a group of farmers.

4.4 Designing plastics for their after-life

Plastics should be designed for their after-life according to the different agricultural uses:

- **Plastic intended to be left in the soil after use: biodegradable plastics**

Plastic that will be left in the soil should be biodegradable to avoid debris accumulation, extra plastic removal and cleaning steps (e.g. plastic mulch and, at a smaller scale, twines to tie vegetables).

Innovation is needed to adapt the degradability to farmers' needs and to environmental conditions. For instance, the FG experts discussed that biodegradability is not only an intrinsic property of plastic but also a result of abiotic and biotic conditions and of the time of degradation. Consequently, the soil biodegradation certificate framed with the EN 17033 standard does not provide sufficient information for farmers across Europe. Indeed, whereas farmers deal with diverse pedoclimatic conditions and diverse cultivation times, the EN 17033 standard evaluates biodegradation in fixed conditions. A biodegradability index, calculated from the specific conditions necessary and the time of degradation would be useful for farmers to choose the best biodegradable plastic for their use.

There is a need for more research on the microbial degradation process in the soil and on its limitations (i.e. the possibility to oversaturate the microbial community with too much biodegradable plastics), or on potential impacts of different climatic conditions, or changes in the soil's natural microbial community.

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Plastic intended to be collected and recycled: strong and recycling-friendly plastics
Plastic should be strong enough to be easily collected and cleaned without producing debris (Figure 12). Different units are used to measure plastic thickness: µm and gauges, 1 µm = 4 gauges. For plastic mulch that is intended to be collected, the experts recommend the use of a film that is thicker than 15 µm (60 gauges). Plastic collection should be preferred over biodegradation for plastics that are used in large quantities (upscaling and standardisation of the recycling processes) and that can be collected in a relatively clean way (little cleaning required). For instance, greenhouse covers and bale wrap for silage. Thin plastics should be avoided if they need to be collected later on, because they produce debris.

Plastics should be designed so that it can easily be recycled (known and standardised polymers and additives).
If recycling is not possible, plastic waste can be valorised by producing char or syngas. The application of char in agricultural soils is an issue of discussion, but char can be used for other purposes such as depollution.

Figure 12: Tool to remove plastic mulch from the field with a tractor. The plastic mulch should be thick and strong enough to resist the removing process.

4.5 Existing plastic collection schemes

Collection schemes connect farmers with recycling facilities and organise the transport of the plastic waste, making it easier for farmers to deal with their plastic waste (Box 2, ADIVALOR). Different countries have implemented different strategies and have tested different solutions. For example, systems where bonuses are given to farmers when they bring their plastic waste to a collection point are very effective, particularly for small farmers. Some countries have a national collection scheme (for example Norway, Sweden, Germany, Ireland) where they manage to reach 70 to 80% of collection thanks to financing of collection schemes. Collection schemes can be organised by different stakeholders. As an example, in Finland farmers' and forest owners' associations take the role of facilitating communication between farmers and other stakeholders (for silage films only because these are clean enough).
Collection schemes may also help to organise additional financial means and compensate the plastic waste market instability. Indeed, the value of plastic waste fluctuates with variations in the price of virgin raw material. Collection schemes can help to buffer the variations of the prices. More information is presented in MP B.

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4.6 Ongoing research projects

Research projects are being developed to fill in knowledge gaps and provide suitable solutions for farmers. The following examples of research projects were presented by the FG experts (Box 5).

Box 5: Examples of existing research projects

Innovative Farmers (https://www.innovativefarmers.org/)

Innovative Farmers is a national British network of farmers and growers who are running on-farm trials, on their own terms. In this network, ten growers are assessing the viability of replacements for polyethylene. The trials will explore a range of commercially available non-degradable and biodegradable solutions, including starch-based film mulches, woodchips, compost (incl. municipal compost), cardboard, hay and grass clippings. The group decided to look at how these mulches will affect weeds, pests, crop performance (e.g. time of harvest, quality of crop), soil moisture, soil health, cost and time/labour.

Organic-PLUS (https://organic-plus.net/)

Organic-PLUS is a H2020 project, running from 2018 to 2022. It studies contentious inputs on organic agriculture, with plastics as one of the main issues. The project includes the testing of a range of biodegradable and non-biodegradable film mulches and their degradable microplastics residues, as well as looking at their technical efficiency, side-effects, environmental impacts, etc. The Organic-PLUS project is also conducting additional trials to investigate the possibility of using on-farm sourced materials (e.g. woodchips, extruded wood or grass clippings). However, it is not known to what extent these alternatives are viable for outsourcing (i.e. buying external material). There are trials on different plots and repetitions, using different mulches. These trials are taking place in the UK and in Turkey (interesting contrast in terms of climate conditions). Trials take into consideration effects during the cultivation season, as well as after harvest.
Some results: biodegradable mulches and Polyethylene Terephthalate (PET) are working well but one of the new materials is too weak and not coloured enough to control the weeds. The black mulches work better for weed control. After harvest, the PET film disappears quite quickly. Even a mulch that breaks before the end of the growing season can still be worthwhile. Results of the soil quality assessments are still to be expected.

AlpBioEco (https://www.alpine-space.eu/projects/alpbioeco/en/home)

This project identifies the economic and ecological potential of agricultural side-products and leftovers (herbs, apples and walnuts). Value chains are investigated and new products are developed, as well as new business models. New products are tested in pilot studies. One of the first results achieved so far concerns biodegradable plastics made from apples. The project fosters eco-innovative practices between farmers and SMEs.

LIFE BIOTHOP (https://www.life-biothop.eu/)

The objective of this project is to replace the polypropylene twines on hop fields with bio-twines made of polylactic acid (PLA), which is produced from renewable resources, and is compostable. The PLA twines are successfully used by farmers and they are composted on the farm with plant materials after the harvest.

GO-ACBD (https://www.acolchadosbiodegradables.es/)

GO-ACBD is an Operational Group that develops techniques that can optimise the degradation process of biodegradable mulch. The group assesses the degradation speed under real conditions in the region of Murcia in Southeast Spain. GO-ACBD aims at improving the competitiveness of agricultural enterprises as well as compliance with principles of the circular economy. Their results suggest that the best degradation is obtained when additional organic matter is applied as manure, when biodegradable plastic is buried into the soil after the harvest and when moisture is kept through irrigation. Therefore they recommend to alter the use of biodegradable mulch for one crop with no mulch applied in the next crop, so that the irrigation of the second crop ensures good degradation conditions for the remaining debris.

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5. Ways forward and recommendations

5.1 Communication: explaining environmental issues, raising awareness and disseminating good practices

Reducing the plastic footprint of agriculture relies on an increase of the awareness and a successful dissemination of good practices. Raising awareness calls for a better understanding of the plastic footprint of agriculture through life cycle analysis of the different agriplastics, and through the assessment of the different sources of plastic contamination and their effects. In the same way, farmers' needs and specific conditions of use should be communicated to the agriplastic industry. In this sense, initiatives like the Innovative Farmers and EIP-AGRI Operational Groups are to be encouraged to foster a successful collaboration between farmers, science and the agriplastic industry. For example, the Operational Groups GO-ACBD made a practical guide presenting the good practices that facilitate soil biodegradable plastic degradation (https://www.acolchadosbiodegradables.es/wp-content/uploads/2020/11/acbd-guia-resumen_b.pdf). They also made a video summarising their activities (https://youtu.be/nSwQUGrmFn8). GO-ACBD based its research on field assessment and relevant agricultural management related to the farms' situation (Figure 13). Other good dissemination practices are presented in MP D.

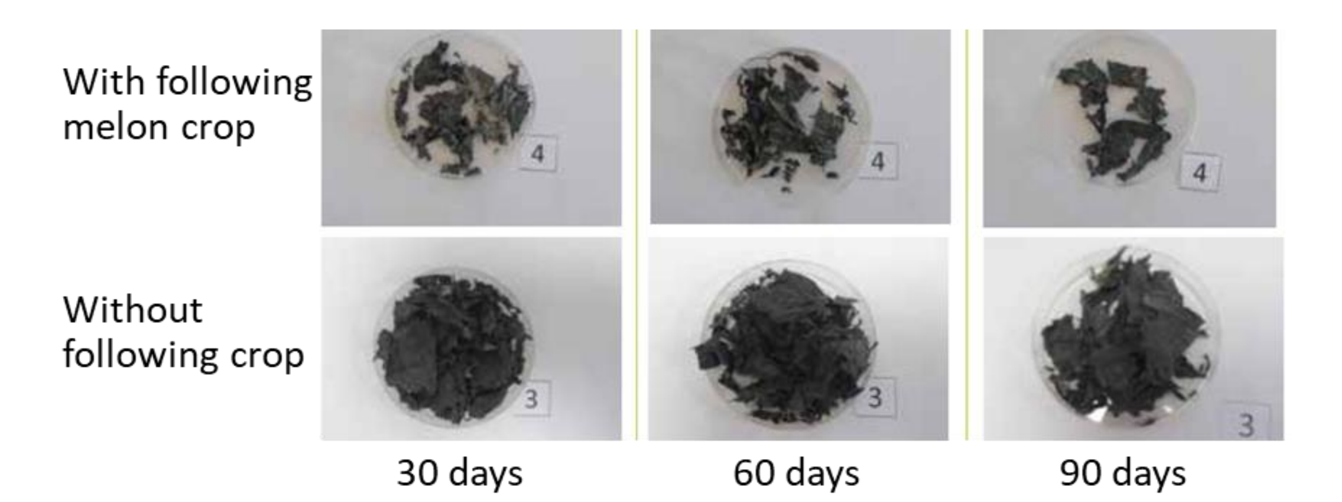
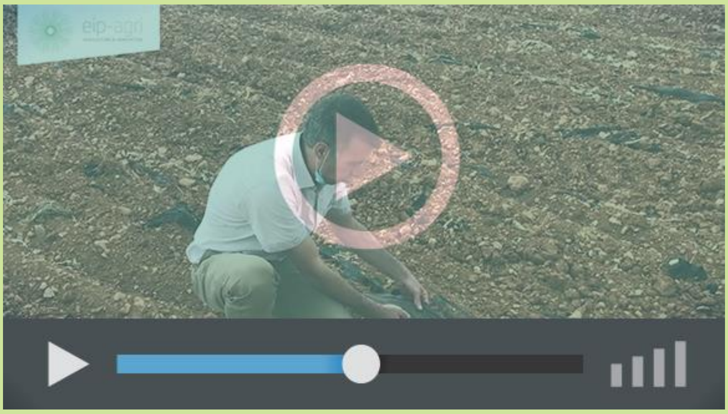


Figure 13 : Degradation assessment of biodegradable plastic after 30, 60 and 90 days after the harvest, and in the presence or absence of a following melon crop (GO-ACBD)



Watch the Operational Group ACBD video, summarising their activities

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5.2 Research needs priorities

Many research gaps and needs for innovations have been discussed previously, and are detailed in the Minipapers. Fourteen ideas are prioritised by the experts in Annex 6. Here we present the five top priorities (Figure 14). The top two ideas relate to the recycling of plastic, highlighting that improving the recycling of agriplastics is a main challenge to reduce the plastic footprint in agriculture.

- **1. Design-for-recycling approach in plastic production to facilitate recycling.** Improving recycling of plastics first requires the use of polymers that can easily be recycled, with few and standardised additives. More resistant plastics are also easier to collect and to handle without fragmenting into small debris. Research for more resistant plastic and easily recyclable plastics has to be combined with research of alternatives to fossil fuel-based plastic, for example converting organic waste into plastic (L. Jiang et al. 2020), in order to reduce the plastic footprint of agriculture.

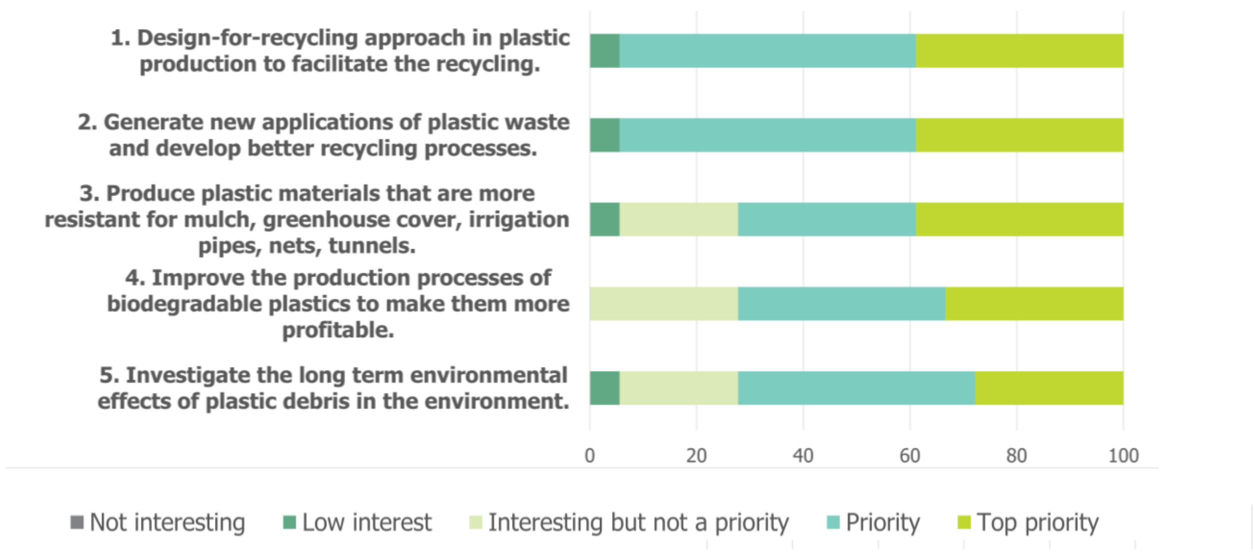

Figure 14: Five top research needs priorities selected out of 14 ideas identified by the Focus Group experts

- **2. Generate new applications of plastic waste and develop better recycling processes.** Directly linked to the design-for-recycling approach, the after-life of plastic should be thought of during the production steps. Recycling processes should be improved to deal with soilage of plastic waste, and to reduce treatment costs. One way to improve the recycling process would be to use microorganisms to degrade plastic into monomers that can be used again by the chemical industries. Microorganism candidates have already been discovered for specific plastic polymers but more research is needed to understand these degradation processes and the use of the resulting monomers (Bahl et al. 2020). Microorganisms could also be used to degrade the contaminants that prevent some agriplastics from being recycled (e.g. pesticide residues, fertilisers) (Arya et al. 2017).
- **3. Produce plastic materials that are more resistant, for mulch, greenhouse covers, irrigation pipes, nets, tunnels.** Stronger materials should be used for agriplastics that are directly exposed to the environment, in order to first limit fragmentation due to weathering and the emission of plastic debris, secondly to increase the life span of these materials when profitable. Understanding how degradation factors (e.g. sunlight, temperature, mechanical torque) influence the size, shape and chemical properties of plastic debris is the first step to reduce the emission of macro and microplastics.

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- **4. Improve the production processes of biodegradable plastics to make them more profitable.** Increasing the profitability of biodegradable plastics relies on two levers: (i) Ensuring that plastics degrade in the desired time for the crop and under the specific conditions of the farm without any negative effects for soil fertility. For that purpose, studies have to be conducted to understand how native soil microorganisms can degrade plastic polymers in specific pedoclimatic conditions. Based on field studies, better degradation tests need to be developed to measure the degradation rate of new biodegradable polymers in real conditions. (ii) Upscaling the production of biodegradable plastics to make them more affordable. New production processes could also rely on microorganisms to produce biodegradable plastics (Medeiros Garcia Alcântara et al. 2020).
- **5. Investigate the long-term environmental effects of plastic debris.** The environmental effects of plastic remain largely unknown. Research on terrestrial organisms, from bacteria, earthworms to mammals, should be performed. The size, shape and chemical properties of plastic debris need to be taken into account, as pristine plastics are likely to have different effects compared to aged ones (S. W. Kim et al. 2020). Moreover, plastic constitutes a new living support and source of nutriments for many microorganisms: this is called the plastisphere (Amaral-Zettler et al. 2020). The effect of plastic on the microbial community, in the soil or in the gut of animals, will undoubtedly impact other organisms such as plants or animals (Qi et al. 2020; Zhu et al. 2018).

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5.3 Operational Group ideas

The following ideas for Operational Groups were proposed by the experts during the second FG meeting:

- Identify the best plastic debris removal techniques for specific agricultural management types
- Realise a life cycle analysis of conventional plastic from virgin material, recycled plastic, bio-based, and biodegradable plastics for specific agricultural uses
- Test different plastic design methods to facilitate future plastic waste recycling
- Optimise plastic cleaning techniques on the farm
- Pros and cons of the use of biodegradable polytunnels
- What are the alternatives to polypropylene thermal blankets?
- Test the usability, durability, and costs of using more resistant plastic in specific agricultural systems
- Large-scale assessment of plastic contamination in agriculture to identify the effects on yield
- Identify best methods and uses of the production of pyrolysis char, based on plastic waste in agriculture

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Conclusions

Plastics are widely used in agriculture, and they provide many services. In many cases, plastics became the most economical solution to sustain high crop production. However, the use of plastics comes with challenges for the management of the resulting plastic waste and environmental contamination with plastic debris.

When discussing the plastic footprint of agriculture, plastic mulch is often used as an example. Indeed, it illustrates the main issues: it is difficult to replace, difficult to recycle because of high soilage, and it opens up the discussion on biodegradable plastics. However, plastic mulch does not represent the main source of plastic waste that is produced in EU agriculture. Silage wrap, greenhouse covers or twines are responsible for more plastic use. Studies also suggest that biofertilisers (sewage sludge, compost) contribute more to microplastic contamination at EU scale than plastic mulch. The Focus Group experts highlighted the diversity of plastic uses in agriculture, and the invisible contamination from microplastics. New studies should take this diversity into account, to increase our overall understanding and to provide solutions to the specificities of EU farming management types.

Farmers play a crucial role in addressing these challenges, for example by reducing the use of plastic when possible, and assuring that no plastic debris is left in the field. On the other hand, many aspects of the plastic footprint of agriculture are independent of farmers' decisions, such as the packaging that is required by food suppliers, the offer of plastic recycling plants in their region, or the availability of alternatives. More specifically, the long-term effects of plastic contamination in the fields are still unknown. Farmers need support to understand the key issues, develop innovative solutions and implement them on a large scale. In the opinion of this FG, reducing the plastic footprint in agriculture requires the collaboration of farmers, plastic industries, researchers, and politicians to ensure the sustainable use of our resources and the protection of the environment.

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Annex 1A: List of the experts and facilitation team participating in the Focus Group

Name of the expert	Professional background	Country
Abelardo Hernández	Other	Spain
Benoit James	Farmer	France
Bernard Le Moine	Industry	France
Carolina Peñalva	Researcher	Spain
Cesare Accinelli	Researcher	Italy
Corina Carranca	Researcher	Portugal
Francis Rayns	Researcher	United Kingdom
Geert Cornelis	Researcher	Sweden
Giovanni Trovati	Farmer	Italy
Ignacio Mendioroz Casallo	Adviser	Spain
Juanjo Amate	Adviser	Spain
Karl Fonteyne	Industry	Belgium
Katja Zlatar	Farmer	Croatia
Krystian Butlewski	Researcher	Poland
Leena Erälinna	Researcher	Finland
Łukasz Czech	Farmer	Poland
Minna Ojanpera	Working at an NGO	Finland
Pietro Picuno	Researcher	Italy
Ruth Pereira	Researcher	Portugal
Vesna Milicic	Working at an NGO	Slovenia
		France

Facilitation team		
Nicolas Beriot	Coordinating expert	France
Liisa Kübarsepp	Task manager	Estonia
Alexandre Morin	Backup	France

You can contact Focus Group members through the online EIP-AGRI Network.
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Annex 2B: List of minipapers

Minipapers	FG members contributing
MP A: The actual uses of plastics in agriculture across EU: An overview and the environmental problems	Ruth Pereira coord. (PT), Abelardo Hernandez (ES), Benoit James (FR), Bernard LeMoine (FR), Corina Carranca (PT), Francis Rayns (UK), Geert Cornelis (SWE), Leena Erälinna (FI), Lukasz Czech (PO) Pietro Picuno (IT)
MP B: The agri-plastic end-of-life management	Bernard LeMoine coord (FR), Leena Erälinna coord (FI), Giovanni Trovati (IT), Ignacio Mendioroz Casallo (ES), Juan Jose Amate (ES), Katja Zlatar (CRO), Krystian Butlewski (PO), Minna Ojanpera (FIN), Pietro Picuno (IT)
MP C: New plastics in agriculture	Francis Rayns coord. (UK), Abelardo Hernandez (ES), Carolina Peñalva (ES), Cesare Accinelli (IT), Corina Carranca (PT), Karl Fonteyne (BE), Katja Zlatar (CRO), Vesna Miličić (SLO)
MP D: Agricultural management, on site practice to reduce plastic use and the contamination in the environment	Benoit James coord. (FR), Carolina Peñalva (ES), Giovanni Trovati (IT), Iñaki Mendioroz (ES), Łukasz Czech (PO), Vesna Miličić (SLO)
MP E: Secondary sources of plastic contamination	Geert Cornelis coord. (SWE), Cesare Accinelli (IT), Francis Rayns (UK), Karl Fonteyene (BE), Vesna Miličić (SLO)

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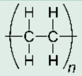
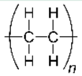
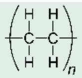
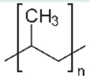
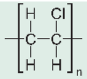
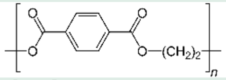
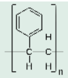
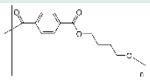
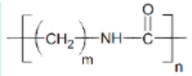
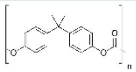
Annex 2: Name, abbreviation, description and share of the EU plastic demand for the most commonly used conventional plastic polymers

Name	Abb.	Chemical structure	Description	Example of use	% of the EU tot. plastic demand	% for agriculture use of the EU tot. plastic demand
Polyethylene	PE		Low cost, good workability, excellent chemical resistance and electrical insulation	With high branching (2% of the Carbons) it produces LDPE, with low branching it produces HDPE	29.7%	1.1%
Low-density polyethylene	LDPE		Low tensile strength	Reusable bags, trays and containers, agricultural film, food packaging film	7.5%	0.1%
High-density polyethylene	HDPE		High tensile strength	Toys, milk bottles, shampoo bottles, pipes, houseware	12.2%	1%
Polypropylene	PP		Properties are similar to polyethylene, but it is slightly harder and more heat-resistant	Food packaging, microwave containers, pipes, automotive parts	19.3%	1%
Polyvinyl chloride	PVC		Can be rigid and flexible depending on the production process and additives used	Window frames, floor and wall covering, pipes, garden hoses	10%	
Polyethylene terephthalate	PET		PET can be semi-rigid to rigid, and it is very lightweight	Synthetic fibres (often referred to as polyester), water bottles	7.7%	
Polystyrene	PS		Polystyrene can be solid or foamed to produce expanded polystyrene (EPS)	Food packaging, insulation	6.4%	0.5%
Polybutylene terephthalate	PBT		PBT has slightly lower strength and rigidity, slightly better impact resistance than PET	Household electrical, insulator		
Polyamides	PA		Polyamides are a group of polymers that differ by the composition of their main chain. Most common polyamide is Nylon	Synthetic fibres, automotive industry		
Polycarbonates	PC		Strong, tough materials, can be optically transparent	Plastic containers, transparent sheeting		

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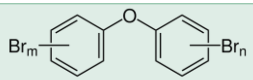
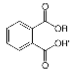
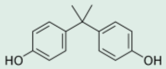
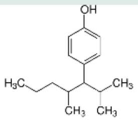
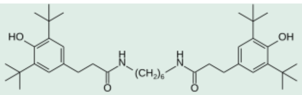
Annex 3: Different families of additives

Name	Chemical structure	Example of use	Potential adverse effect
Polybrominated diphenyl ether (PBDEs)		Family of additives for different use, including flame retardants	Endocrine disruptors
Phthalates		Family of additives for different use, including increase plastic flexibility, transparency	Endocrine disruptors
Bisphenol A		Precursor for plastic polymerisation, Antioxidant (reduce degradation)	Endocrine disruptors
Octylphenol and Nonylphenol		Family of additives for different use, including Antioxidants (reduce degradation)	Endocrine disruptors
Irganox		Antioxidant (reduce degradation)	Endocrine disruptors

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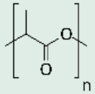
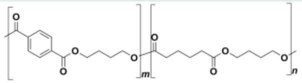
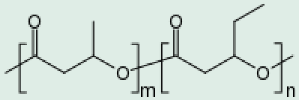
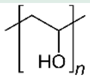
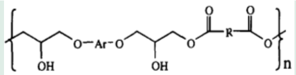
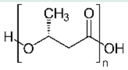
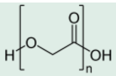
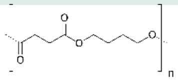
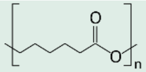
Annex 4: Name, abbreviation, description and degradability of biodegradable polymers

Name	Abb.	Chemical structure	Description	Example of use	Degradation	Soil burial test
Polylactic acid	PLA		Bio-based from fermented plant starch such as corn, cassava, sugarcane or sugar beet pulp.	Packaging, agricultural films, synthetic fibres, nonwoven fabrics,	Biodegradable under industrial composting. Very slow to no degradation at ambient temperature in soil	(Shogren et al. 2003) (Lv et al. 2017) (Rudnik and Briassoulis 2011a) (Rudnik and Briassoulis 2011b) (Calmon et al. 1999) (Siakeng, Jawaid et al. 2020)
Polybutylene adipate terephthalate	PBAT		High flexibility and toughness, low stiffness	plastic bags, agricultural films and wraps	Biodegradable under industrial composting conditions. Slow degradation at ambient temperature in soil	(Palsikowski et al. 2018) (H. Wang et al. 2015) (Weng et al. 2013)
Poly(3-hydroxybutyrate-co-3-hydroxyvalerate)	PHBV		Low elongation and low impact resistance	CRF, packaging	Biodegradable under industrial composting conditions. Slow degradation at ambient temperature in soil	(Calmon et al. 1999) (Sang et al. 2001) (S. Wang et al. 2005) (Gonçalves et al. 2009) (Tao et al. 2009) (Batista et al. 2010) (Gonçalves and Martins-Franchetti 2010) (Arcos-Hernandez et al. 2012) (Baidurah, Murugan et al. 2019)
Polyvinyl alcohol	PVA		High tensile strength and flexibility	Use as a moisture barrier in plastic films	Very limited degradation at ambient temperature in soil	(Corti et al. 2002)
Poly(hydroxyester-ethers)	PHEE		high thermal and chemical resistance.	improve the mechanical and water resistance of a blend	Slow degradation at ambient temperature in soil	(Shogren et al. 2003)
Polyhydroxyalkanoates	PHA		Similar to PP	packaging	Slow degradation at ambient temperature in soil	(Rudnik and Briassoulis 2011a) (Chan, Vandi et al. 2019) (Umesh and Thazeem, 2019)
Polyglycolide	PGA		high strength and stiffness	packaging		
Polybutylene succinate	PBS		Similar to PP	packaging	Slow degradation at ambient temperature in soil	(Kim et al. 2006) (Wang, Liu et al. 2020)
Polycaprolactone	PCL		good resistance to water, oil, solvent and chlorine	improve processing characteristics and impact strength of a blend	Almost full soil degradation	(Calmon et al. 1999) (Al Hosni, Pittman et al. 2019)

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Annex 5: Abundance of microplastics in environmental samples

Matrix	Description	Abundance [g kg^{-1}]	Abundance [particles kg^{-1}]	References
Soil	Near the industrial area in Australia	0.3–67		Fuller and Gautam (2016)
Soil	Floodplain soils in Switzerland	0.055	≤ 593	Scheurer and Bigalke (2018)
Soil	Vegetable fields in China (Shanghai)		78.0 ± 12.9 (top layer) 62.5 ± 13.0 (deep layer)	Liu et al. (2018) b
Soil	Agricultural field in China (Shanghai)	≤ 0.00054	40 ± 126 (top layer) 100 ± 141 (deep layer)	Zhang et al. (2018) b
Soil	Greenhouse field in China (Shanghai)	≤ 0.00054	100 ± 254 (top layer) 80 ± 193 (deep layer)	Zhang et al. (2018) b
Soil	Greenhouse vegetable soils in China (Shanghai)		7100–42,960	Zhang and Liu (2018)
Soil	Forest buffer zone in China (Shanghai)		8180–18,100	Zhang and Liu (2018)
Soil	Sewage sludge application in Chile		600- 10400	Corradini (2018)
Soil	Soils amended with sewage sludge and compost in citrus orchard, China		545.9 ± 45.7 (after 30 t/ha/y sludge) 87.6 ± 9.3 (after 15 t/ha/y sludge)	Zhang et al. (2020)
Soil	Mulching in cropped soils in China (Hangzhou Bay)		263	Zhou et al. (2020)
Soil	Mulching in vegetable cultivation in Murcia, Spain		2116 ± 1024	Beriot et al. (2020)
Soil	Soils amended with sewage sludge in east of Spain		18,000 ± 15,940 light density plastic 32,070 ± 19,080 heavy density plastic	(van den Berg et al. 2020)
Wetland	Urban tidal freshwater wetland in USA (Washington, DC)		1,270 ± 150	Helcoski et al. (2020)
Biota	earthworm, Lumbricus terrestris, exposed to microplastics in petri dishes	4.5 ± 2.5		Huerta Lwanga et al. (2016)
Biota	Terrestrial birds China (Shanghai)		22.8 ± 33.4 per bird, 0-116 per bird	Zhao et al. (2016)
Biota	Microplastic in sheep faeces in Murcia, Spain		997 ± 971	Beriot et al. (2020)
Sludge	municipal treatment plant in New York, US		0 – 2000	Zubris and Richards (2005)
Sludge	municipal treatment plant in California, US		5000	Carr et al. (2016)
Sludge	municipal treatment plant in Ireland		4200 – 15000	Mahon et al. (2017)
Sludge	municipal treatment plant in Chile		34000	Corradini (2018)
Air	Urban and sub urban sites in Paris		2–355 particles/m^2/day	Dris et al. (2016)
Drinks	Beer, Bottled water, Tap water		32.27, 94.37, 4.23 particles L^{-1}	Cox et al. 2019
Food	Seafood, Sugar, Honey, table salt		1.48, 0.44 , 0.10, 0.11 particles g^{-1}	Cox et al. 2019

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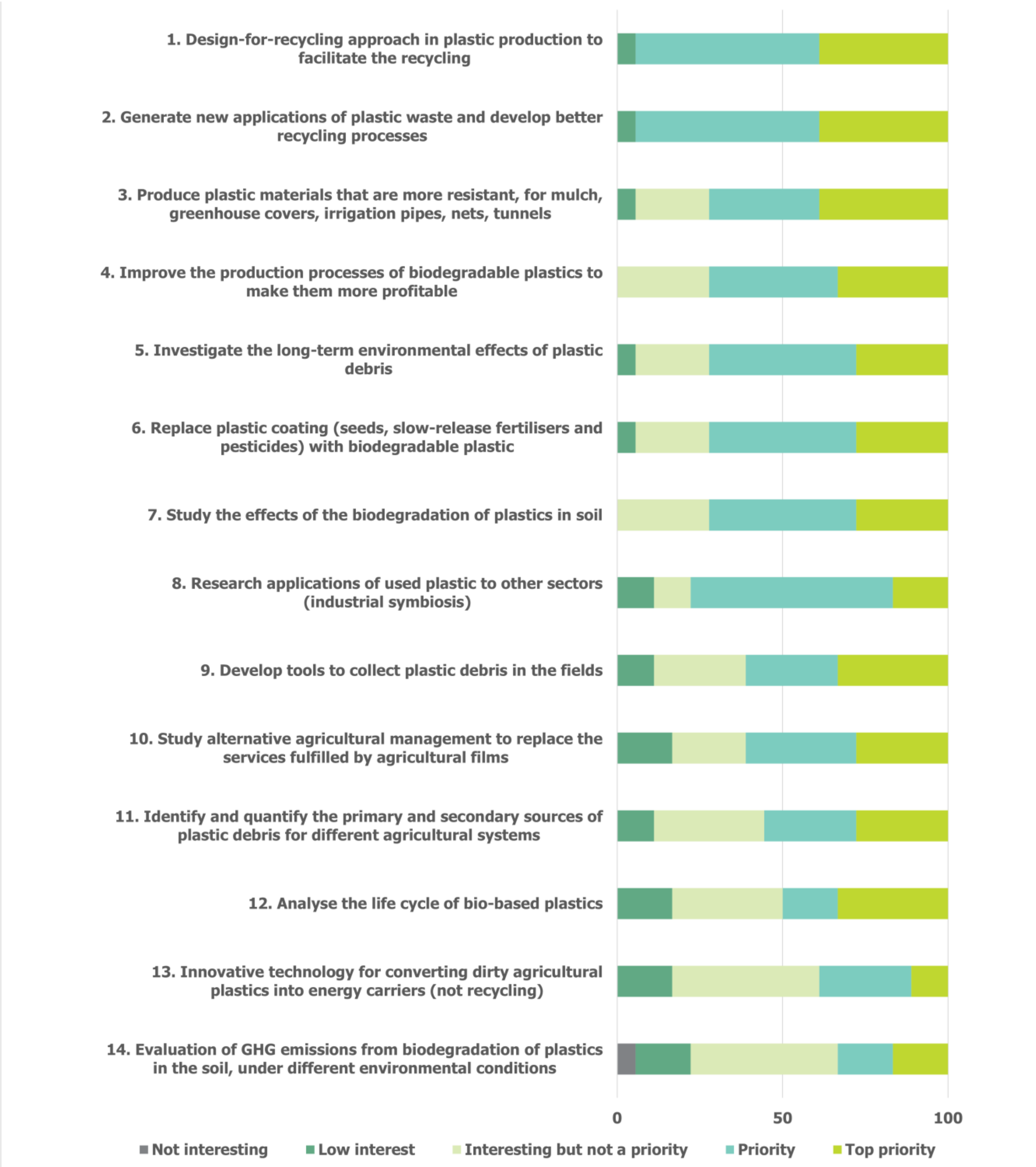
Annex 6: Research needs identified and prioritised by the Focus Group experts. Eleven out of the fourteen suggested ideas are considered priorities by more than half of the experts.



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The **EIP-AGRI** aims to catalyse the innovation process in the **agricultural and forestry sectors** by bringing **research and practice closer together** – in research and innovation projects as well as *through* the EIP-AGRI network.

EIPs aim to streamline, simplify and better coordinate existing instruments and initiatives and complement them with actions where necessary. Two specific funding sources are particularly important for the EIP-AGRI:

1. the EU Research and Innovation framework, Horizon 2020,
2. the EU Rural Development Policy.

An EIP AGRI Focus Group* is one of several different building blocks of the EIP-AGRI network, which is funded under the EU Rural Development policy. Working on a narrowly defined issue, Focus Groups temporarily bring together around 20 experts (such as farmers, advisers, researchers, up- and downstream businesses and NGOs) to map and develop solutions within their field.

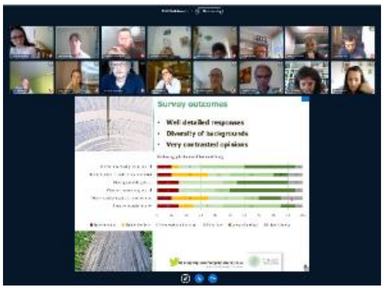
The concrete objectives of a Focus Group are:

1. to take stock of the state of art of practice and research in its field, listing problems and opportunities;
2. to identify needs from practice and propose directions for further research;
3. to propose priorities for innovative actions by suggesting potential projects for Operational Groups working under Rural Development or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.

Results are normally published in a report within 12-18 months of the launch of a given Focus Group.

Experts are selected based on an open call for interest. Each expert is appointed based on his or her personal knowledge and experience in the particular field and therefore does not represent an organisation or a Member State.

*More details on EIP-AGRI Focus Group aims and process are given in its charter on:
http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf



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