Agricultural plastic waste in Finland

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Abstract

Agricultural plastic waste in Finland

This report discusses the present situation regarding waste handling and recycling of agricultural and horticultural plastic waste in Finland. Primary focus is on materials that form the main volumes of used agro-plastics, including haybale wraps (stretch films), haybale nets, clamp sheets, horticultural fleece, mulch films, irrigation pipes, and agricultural packaging materials such as fertilizer bags, canisters or other product packaging. The report delineates the main material composition and use of these plastics, and their technical feasibility for mechanical recycling. The study presents the regulatory framework for agro-plastics waste handling, including the critical role of Extended Producer Responsibility (EPR) under the Finnish Waste Act 646/2011, existing voluntary material collection and recycling schemes, and the operational functions of (selected) companies involved in agro-plastics waste handling and recycling. The main barriers to effective recycling of agro-plastics include high waste material collection costs in sparsely populated regions, and handling practices at farms. The study recommends enhancing source sorting with awareness raising and recycling guidelines, and specifically expanding collection infrastructure to achieve feasible recycling rates and circular economy goals towards sustainable development.

Keywords: Agricultural plastics; Extended Producer Responsibility (EPR); Circular economy; Mechanical Recycling

Tiivistelmä

Maatalousmuovijäte Suomessa

Tämä raportti käsittelee käytöstä poistettujen maa- ja puutarhatuotannon muovien käsittely- ja kierrätystilannetta Suomessa. Päähuomio on materiaaleissa, joiden käyttövolyymi on suurin: paalimuovit (kiristekalvot), paaliverkot, aumamuovit, suojaharsot, katekalvot, kasteluletkut sekä maatalouden pakkausmuovit, kuten lannoitesäkit, kanisterit ja muut tuotepakkaukset. Raportissa kuvataan näiden muovien materiaalikoostumus ja käyttö sekä materiaalin tekninen kierrätettävyys mekaanisen kierrätyksen avulla. Raportissa esitellään maatalousmuovijätteen käsittelyn sääntely, mukaan lukien laajennettu tuottajavastuu osana jätelakia (646/2011), olemassa olevat vapaaehtoiset materiaalien keräys- ja kierrätysjärjestelmät sekä keräys- ja kierrätystoiminnassa mukana olevien (valittujen) yritysten toiminta. Maatalousmuovien tehokkaan kierrättämisen pääesteet ovat korkeat noutokustannukset harvaan asutuilta alueilta ja muovien käsittelykäytännöt maatiloilla. Tutkimuksen tulosten perusteella muovien syntypaikkalajitteluun ja viljelijöille suunnatun lajitteluohjeistuksen antamiseen sekä erityisesti keräysjärjestelmän laajentamiseen tulisi panostaa, jotta muovien kierrätysasteen nostaminen ja kiertotalouden tavoitteiden saavuttaminen osana kestävää kehitystä olisi mahdollista.

Asiasanat: Maatalousmuovit, laajennettu tuottajavastuu, kiertotalous, mekaaninen kierrätys

Contents

1 Introduction

A wide variety of plastic products are needed in agricultural and horticultural production for various purposes. The most typical plastics used in agriculture are wrap films and nets used for hay and/or silage production, clamp sheets in silage production, mulch films used for eradication of weeds and enhancing moisture and temperature conditions, and various packaging plastics intended for the storage and transport of production inputs, such as big bags for seeds and canisters for pesticides. In horticultural activities, plastics are used to support the cultivated plants (such as seedling trays, soil covers and plant support strings), and in the structures of greenhouses (such as irrigation channels, shades and tunnel materials). These products are made of several types of polymers.

Plastics have been increasingly used in agriculture since 1950s, firstly in intensive greenhouse and specialized crop production in core agricultural areas in the USA and central Europe. Plastic use in all agricultural and horticultural sectors has increased both globally and in Finland especially during the last two decades. Global use of plastics in agriculture is approximately 12.5 million metric tons annually and majority of the use takes place in Asia (Food and Agriculture Organization of the United Nations FAO 2021). In Europe, over 1 million tons of agro-plastic wastes are generated annually (APE Europe 2025). Mulch, silage and greenhouse films represent 60 % of the total agro-plastic volumes both globally and in Europe (FAO 2021; Gerassimidou & Iacovidou 2024). According to previous studies, Finnish farms generate approximately 12 000 tonnes plastic waste in their operations annually (Erälinna & Järvenpää 2019; Selonen et al. 2023). These figures include also agricultural packaging waste.

The increasing use of plastics in agriculture has created an expanding waste problem. Agro-plastic recycling rates are very low: less than 10% of it is recycled globally (Hofmann et al. 2023). In Europe, the agro-plastic recycling rate varies markedly between countries (Felipe et al. 2023). Countries with a well-established national collection scheme such as Ireland, Iceland, Norway, Sweden, France, and Spain have achieved a high collection rate reaching up to 70%. As a material usually consisting of a single plastic grade (polyolefin), agro-plastics could be more easily recyclable compared to many packaging materials. However, problems with organising the collection and the characteristics and quality of the material resulting high processing costs hinder their recovery and valorization (Hann et al. 2021).

The type and size of the agricultural and horticultural business affect the type and amount of plastic use and waste generation: how much and at what time of year it is generated. For example, on livestock farms animals need feed (e.g hay bales) daily, so wrap film waste is generated every day throughout the year (except grazing season from May to early September). On the contrary, in open air horticulture horticultural fleece and mulch films are typically used for 3 to 5 years, so plastic waste is generated less frequently. Finland has separate waste management systems for municipal and industrial wastes. Agricultural waste in Finland is classified as industrial waste, and it is not accepted at municipal collection points or waste stations aimed for households. Contrary to a centrally organized, separate kerbside collection for different fractions of municipal wastes (mandatory) for the larger housing units in the densely populated areas, waste handling for private businesses (including farms) is based on individual service contracts with private waste management companies. According to Waste Act, each farm (as a waste holder by the Act) must ensure that the plastic waste it produces is appropriately delivered to industrial waste reception facilities. This means organizing also the transports to a waste reception terminal either by buying the service from a (licenced) waste management company, or taking the different wastes there by own vehicle.

In Finland only agricultural packaging plastics are subject to the Extended Producer Responsibility (EPR) included in the EU Waste Directive (2008/98/EC) and Finnish Waste Act (464/2011, §46-48). Based on EPR, the (domestic) manufacturers, importers and sellers of recyclable materials, including also plastics, are responsible for organizing reception facilities and recycling for these materials after they are no longer used. Based on the EPR, these materials are accepted at reception facilities for industrial plastic waste free of charge if the material is correctly source separated. Associated costs are included in product prices. Agricultural packaging plastics include packaging for various production inputs, such as fertilizer and seed bags, lubricant and pesticide canisters, and plastic cores for plastic film rolls. Since these different plastic packages are typically made of different plastic grades, in order to ease their recycling each of them must be sorted into their own batches as well as possible, preferably right after use at the farm. Recyclable plastic waste must also be stored properly to keep it as clean and dry as possible, so that it can be accepted for recycling. Dirty agricultural or horticultural plastic waste is only suitable for incineration for combined heat and electricity production. When EPR legislation was implemented in Finland (in 2015), landfilling of recyclable materials was banned.

From the perspective of an individual farmer or horticultural entrepreneur, the most significant challenge in recycling of agricultural and horticultural plastic waste is the question where to take plastic waste for recycling or disposal purposes? And what would it cost? A vast majority of agricultural and horticultural plastic waste is generated in sparsely populated areas where the transport cost for the direct collection of the waste from a farm or a household is significantly higher compared to densely populated urban areas. To optimize waste handling logistics, the regional waste reception and handling terminals for both industrial and municipal wastes are located in the vicinity of urban areas. As a result, agricultural and horticultural plastic waste must be transported over long distances to the nearest waste terminal, which significantly increases the costs. If the waste holding farmer is not able or willing to organize the delivery of his/her plastic wastes either to recycling or to incineration plants, the waste usually accumulates on farms in considerable piles, which are often still collected in hidden, remote places, out of sight of other people. Over the years, these piles of plastic waste become unsuitable for recycling, so they can no longer be collected later except for incineration in thermal power plants (Pönni 2023).

To help farmers to get rid of their plastic waste, a voluntary collection and recycling scheme created by Suomen Maatalousmuovien Kierrätys Oy started collecting recently used haybale wrap films directly from farms in 2024 and expanded the collection to clamp sheets in 2025 (Suomen Maatalousmuovien Kierrätys Oy 2025). The scheme implements EPR on a voluntary basis. Similar schemes are in operation elsewhere in Europe, and the creators of the Finnish scheme have learned from their experiences. Even prior to that scheme, a voluntary (annual) collection campaign for used fertilizer bags organized jointly by a fertilizer producer and 4H has been in operation continuously since 1975 (Suomen 4h-liitto 2025).

For other agricultural plastics with considerable volumes used, including non-packaging horticultural plastics, such a systematically organized collection is lacking in Finland. Waste management companies do accept non-packaging agricultural plastics materials as mixed energy waste in their reception facilities but charge a handling fee or gate fee to cover handling costs. The waste management companies process and deliver mixed energy waste to combined heat and energy production. To encourage the waste hierarchy targets of waste minimization and recycling, the gate fees are graded depending on how the plastic waste is processed in later stages. Materials that are accepted in the terminals as recyclable materials have lower gate fees compared to materials that are considered as energy wastes.

This report provides an analysis and guidance of the agricultural and horticultural plastic waste and how those should be handled for improving the recycling of this waste. The report presents the results of the PlastLIFE SIP Task T.5.3.1 “Material study on the recycling potential of agricultural and horticultural plastics”, which aims at identification of the recovery and recycling potential for the different plastic materials used in agriculture (especially plant production) and horticulture. The task specifically focuses on such plastic materials that are currently not collected for recycling. University of Turku (UTU), Finnish Environment Institute (Syke) and Lab University of Applied Sciences (LAB) have carried out the research which this report is based upon. UTU project specialist Veijo Pönni and Ph.D researcher Aaqib Mohammed have written parts 1,2,3,6 and 7 of this report. Chief specialist Pekka Laurikainen, Principal lecturer Reijo Heikkinen and Project manager Juha Hildén at LAB conducted the recycling tests reported in part 4, and Pekka Laurikainen wrote the text in part 4. Finnish Environment Institute

(Syke) chemist Hanna Niemikoski and researcher Timo Sara-Aho are responsible for chemical analysis and principal researcher Matti Leppänen and researcher Johanna Järvistö for toxicological analysis presented in part 5. In addition, senior researcher Salla Selonen analysed bioassays for earthworms. University teacher, Dr. Johanna Yliskylä-Peuralahti (UTU) has been responsible for project management for the work and editing this report. We wish to thank warmly the companies, farms and other informants who gave us vital information in the form of interviews and allowed us to visit their premises. Special thanks also to all those persons who provided assistance in laboratory analysis.

2 Agricultural plastics

2.1 Haybale wrap films

Haybale wraps are used to preserve animal feed, such as hay and silage, and protect them from moisture, UV light, and contamination. The wraps help to maintain the nutritional quality and enabling outdoor storage of the feed, which is essential in varying weather conditions in the Northern agricultural regions. The wraps are made of low-density linear polyethylene (L-LDPE) which is flexible, durable, and UV-resistant. This type of plastic material supports anaerobic fermentation in silage production because it creates a protective, firm layer around the bale.

Presently, most haybale wraps are recycled mechanically. Mechanical recycling of various types of agro-plastics is favoured due to its low carbon footprint and its role in minimizing overall environmental impact. A primary benefit of mechanical recycling is its capacity to transform plastics waste into a resource to be used in new products, and thereby helping to reduce virgin plastics use and support circular economy. The recycling process for haybale wraps (Figure 1) encompasses the following stages: source sorting and storage at the farms followed by collection and transport to a recycling facility. The source sorting is vital since it ensures that the recycling facility receives only homogeneous plastic material consisting only one plastic type or grade. At the recycling plant, the material undergoes cleaning, shredding, and melt processing into plastic granulates.

Figure 1. The mechanical recycling process of L-LDPE haybale wraps

Enabling recycling starts on farms after the wraps are no longer used and have been removed from bales. The source sorting instructions for the haybale wraps are provided by Suomen Maatalousmuovien Kierrätys Oy (2024). The guidelines specify that white plastics must be separated, while plastics of other colours may be mixed. However, all transparent bale wraps can be combined with white plastics.

It is imperative that the sorting process, as outlined in the guidelines, is conducted immediately after use, categorized by plastic type, and that the sorted plastics are preferably stored on a dry and solid surface. It is vital that the plastics are stored away from moisture and contact to soil or other debris by keeping them e.g. in bins or bags. When the transport company comes to pick-up the used wraps, the driver decides whether they are correctly sorted, clean enough and thus acceptable for recycling.

Figure 2. Plastic bale wrap waste stored outdoors (Veijo Pönni, 2022)

Figure 3. Loading bale wrap waste (Veijo Pönni, 2022)

At the recycling facility, shredding, washing to remove the residues and metal detection takes place. Finally, the cleaned L-LDPE flakes are melted and processed into plastic pellets in an extruder (Fig. 4).

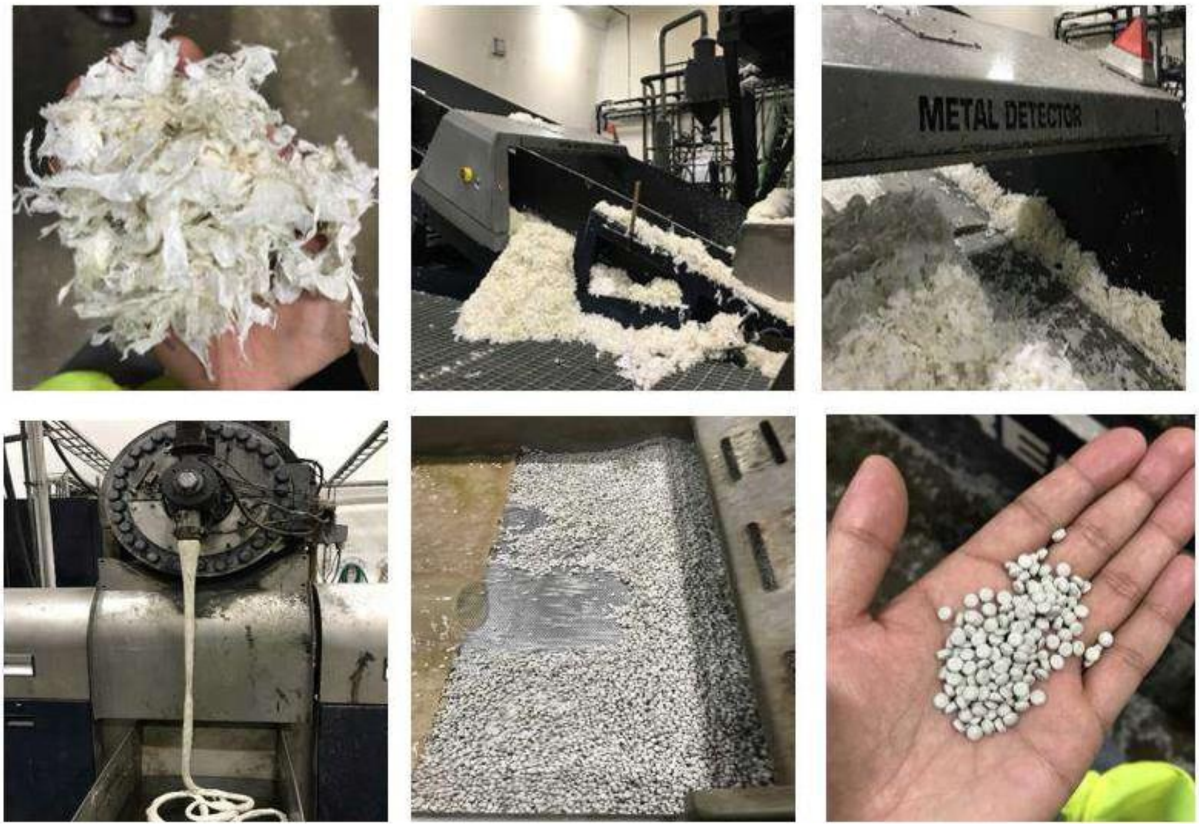

Figure 4. Recycling process of haybale wraps at Clean Plastic Finland (Aaqib Mohammad, 2024)

2.2 Haybale nets

Nets are used to encapsulate hay, other forage, bedding materials (e.g., straw), or non-food crops into bales, as these mesh structures envelop the plant material easing the material handling and mitigating product loss by securely containing and compressing the hay within the bale (Conved n.d.) (Figure 5, next page). However, the net does not prevent moisture entering the bale, so for water protection a bale wrap is also needed. As majority of the netting material is composed of synthetic, non-biodegradable plastics like polyethylene (PE) or polypropene (PP), their use can pose disposal challenges that may lead to environmental contamination. For instance, if the netting is left in the field or improperly disposed of, it can degrade into microplastics, which can significantly impact soil health and fertility. Furthermore, if the discarded netting remains in the field for an extended period, it can become hazardous to livestock and other animals (Briassoulis et al. 2023). Presently, haybale nets are not recycled in Finland and there is no collection scheme for them either. As the nets are durable material, they could be reused as temporary fencing for small animals, as erosion prevention mats, and to support climbing plants such as cucumbers and beans.

Figure 5. Plastic net on a haybale (Johanna Yliskylä-Peuralahti, 2026)

2.3 Clamp Sheets

Clamps are horizontal silos used for storage of silage. Clamp sheets are utilized as plastic covers for the storage of silage, offering an airtight seal to preserve forage quality and minimize losses. The plastic sheet helps to maintain aerobic conditions necessary for proper fermentation which preserves the fodder (Figure 6). Two separate layers of films are usually used: a top layer and an underlayer film that is used as oxygen barrier. The oxygen barrier film is used to seal the silage clamp as tightly as possible against entry of oxygen (Visscherholland 2025). This is good for the fermentation process and helps to maintain the silage in good condition. The oxygen barrier films are made of linear low-density polyethylene (L-LDPE) and the top layers from high-density polyethylene (HDPE). Some producers offer also single-sheet products that are multilayered coextrusions that combine PE layers with an integrated oxygen barrier layer, such as ethylene vinyl alcohol copolymer (EVOH) (Silostop Agri 2022).

Figure 6. Opened indoor hay clamp with pieces of cover film (Hanna Kivistö, 2026)

The challenges associated with recycling clamp sheets primarily arise from organic contamination, such as silage residues and soil. Consequently, it is necessary to clean the film prior to recycling.

Mechanical recycling of the clamp sheets can be effectively conducted under specific conditions, particularly when the composition of ethylene vinyl alcohol (EVOH) in clamp sheets is below 5%, and the tie layers exhibit compatibility. Under these circumstances, it is feasible to integrate the materials into low-density polyethylene (LDPE) recycling streams (RecyClass 2019).

2.4 Horticultural fleece

Horticultural fleece is frequently employed to safeguard early plantings, such as potatoes and seedlings, from frost occurring in the early spring and also in the end of the growing seasons in Northern agricultural regions with a cold climate. Generally, the use of fleece extends the growing season by two to three weeks at both the beginning and end of the season. In the warmer, temperate climatic conditions fleece is mainly used to protect plants from excess sunlight and draught. Besides micro-climatic temperature control, fleece also helps moisture retention and pesticide control. It is typically utilized to cover open air plantations, outdoor green low tunnels, and as a lightweight insulation or shading in greenhouses. The material is composed of polypropylene (PP) or polyester (PE). It can be easily positioned and removed, and with proper maintenance, it can last for three to four years.

Figure 7. Horticultural fleece at a farm in Turku (Aaqib Mohammad, 2025)

Horticultural fleece could be mechanically recycled, but currently there are no facilities to it in Finland. All fleece that is collected from farms in Finland ends up in energy production (usually in the form of mixed waste). To enhance recycling efficiency, minimizing contamination by shaking off soil, avoiding the mixing of materials, and ensuring storage in dry locations is recommendable. To enhance the recycling of horticultural fleece, it is imperative to simultaneously promote extended producer responsibility (EPR) and eco-design to make the material better recyclable.

Figure 8. Picking up horticultural fleece / gauze waste (Veijo Pönni, 2022)

2.5 Mulch films

Mulch films are employed in horticultural crop cultivation to enhance optimal growing conditions, thereby ensuring plant health and fostering the prerequisites for crop yield by improving water retention and temperature regulation. The composition of the mulch film primarily consists of a thin layer of plastic which is applied to the soil surface surrounding the plant. Most of the mulch films are made of low-density polyethylene (LDPE) (Tuohuoa Plastics n.d.) (Figure 9).

Figure 9. Strawberry field layered with mulch films (Hanna Kivistö and Roosa Saarinen 2024)

However, the continuous use of plastic mulch films can lead to the soil health degradation and cause a barrier to the natural movement organisms and water within the soil profile. The application of plastic mulch films in agricultural practices also introduces micro and nano plastics (MNP) to soil environments, especially when removing the plastics from the ground (Selonen et al. 2023). Thus, FAO (2021) has given a recommendation to avoid mulch when possible, and replace it with other non-plastic, biodegradable materials. The secondary solution to combat the negative consequences resulting from the utilization of plastic mulch films is to enhance their proper removal from the ground after use without leaving fragments and enhancing their recyclability by cleaning and sorting the used films, and finally transferring them to the recycling facility (Hann et al. 2021).

To mitigate microplastic contamination in soil, biodegradable plastic mulches are currently regarded as a substitute for conventional plastic mulches. Some farmers in Finland are already using them. However, substantial knowledge gaps persist concerning the long-term effects of biodegradable plastic mulch use on soil ecosystems and their relationship to crop productivity. This distinction is critical because temperature, moisture, and microbial activity—all of which influence biopolymer degradation—differ significantly geographically between different agricultural regions.

2.6 Irrigation Pipes

Irrigation, defined as the artificial application of water to soil, plays a pivotal role in the agricultural sector by ensuring consistent crop growth, particularly in arid and semi-arid regions where it is indispensable for farming. The regular implementation of irrigation systems in agriculture maintains optimal soil moisture, which is essential for plant growth. In contemporary agriculture, irrigation enhances overall production, increases annual yield, and broadens farming opportunities. The main irrigation methods in agriculture include drip (Figure 9), sprinkler and sub-surface irrigation (Agriplastics community 2021).

Figure 9. Drip irrigation pipes on a salad bed (Hanna Kivistö 2026)

The widespread adoption of plastic piping for irrigation purposes can be attributed to several compelling benefits such as durability, flexibility, and resistance to corrosion. Typically, the irrigation pipes are made of low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polyvinyl chloride (PVC). Plastic piping materials have gained widespread adoption owing to their numerous advantages. The longevity of pipes is influenced by various factors, including material composition, exposure to ultraviolet (UV) light, chemical interactions, and other physical stresses such as soil weight and the use of farming equipment. Consequently, pipes that are properly manufactured can last over 20 years under ideal conditions (Fitwell 2025).

Figure 10. Used irrigation pipes waiting for recycling (Aaqib Mohammad, 2024)

After use, pipes can be mechanically recycled into similar pipes, or lower-grade plastic products such as roadside barriers, or fence posts. Some sellers already offer pipes that are made from 100% recycled materials and fits for many industrial application (e.g., agriculture and mining industries). However, in Finland there is no collection scheme in place for agricultural irrigation pipes.

2.7 Agricultural Packaging Materials

In agricultural and horticultural production, canisters, sacks and other packaging materials (e.g., pallet covers) are frequently used for the storage, transportation, and handling of inputs such as seeds, pesticides, and fertilizers. The material composition of canisters comprises of high-density polyethylene (HDPE) or polypropylene (PP) and are available in different sizes from 1 to 25 liters. Flexible intermediate bulk containers, commonly referred to as super sacks or bulk bags, are large bags utilized for the storage and transportation of bulk materials such as fertilizers, seeds, lime, turf and horticultural cover materials (e.g., wood chips).

Figure 11. Bulk material bags (left) and plastic canister (right) (Johanna Yliskylä-Peuralahti, 2025)

The bulk bags often contain two nested bags: an outer and an inner bag. The outer bag is typically polypropylene (PP) and the inner bag polyethene (PE). Both materials can be recycled. Bulk bags, canisters and other agricultural packaging plastics are subject to extended producer responsibility (EPR) (SUMI Oy 2024). Farmers can bring correctly sorted and clean agricultural packaging plastics to industrial packaging waste terminals where used plastics are accepted free of charge. Hence, farmers should adhere the sorting guidelines of plastic packaging and initiate the recycling process for packaging plastics by following the storing and source sorting guidelines. In addition to the collection terminal network based on EPR, there is an annual (voluntary) collection for fertilizer bags in Finland each spring. It is organized by fertilizer producer Yara and 4h (Suomen 4h-liitto 2025).

Contamination can significantly impact the efficiency of recycling for agricultural packaging materials; for instance, if used canisters from farms are not properly cleaned, it can adversely affect the rate and integrity of the recycled material. Plant protectant canisters and other containers of hazardous materials must be adequately rinsed and caps must be removed before the canisters are taken to the collection point. Reuse of the sacks can be determined through different creative and practical ways:

- Storage sacks can be utilized as compost bags.
- The sacks may be filled with soil to construct raised garden beds, offering a convenient method for cultivating vegetables and flowers.
- Additionally, the sacks can serve as weed suppression mats, aiding in the prevention of weed growth in gardens and landscaped areas (Guide to Recycling PP Supersacs, 2018a).

Polymer asphalt, which incorporates sacks as a component in its production, serves as an effective binding agent. This plastic binding agent is known to enhance the asphalt's resistance to temperature fluctuations (Horttanainen et al., 2007).

2.8 Section summary: the technical recyclability of agro-plastics

The majority of the used agro-plastic materials collected in the agro-plastic collection and recycling schemes in Europe ends up in the same or similar agro-plastic products after being recycled (Plastic Recyclers Europe & ICIS 2023.) After recycling, agro-plastics become post-consumer recycled plastics (PCR).[1] These materials are reprocessed plastics originating from household and commercial waste. They have been collected, sorted, and processed to be used as recycled raw material in manufacturing of new products (Alcion 2024). The largest groups of PCR by material volumes (often referred as main grades) (British Plastics Federation 2025) are polyethylene (PE), polypropylene or polypropene (PP), high-density polyethylene (HDPE), and low-density polyethylene (LDPE) (Britannica 2025). The majority of agro-plastics consist of these materials (Table 1, next page). Most agro-plastic materials can be recycled by already existing mechanical recycling methods and there are several product categories where the recycled granulate could be used.

The PCR granulate made of used haybale wraps together with virgin plastics is used in the production for new wraps and/or other film materials. Many European film producers use 25–30% recycled material content in their products. The same situation applies to agricultural packaging plastics: the PCR

[1] In contrast to post-consumer plastics, post-industrial recycled plastics (PIR) are materials discarded in industrial processes that do not reach the market for final consumer sale. They include production waste, cut-offs, or scraps from manufacturers using plastic in their production processes. Post-industrial plastic is typically homogenous material with good quality and can be recycled and re-used in the same production process, or for the creation of new plastic products (Alcion 2024).

made of them is used in making of new packaging materials, industrial parts, and also composites. As an example, the outer layers of the fertilizer bulk bags containing PP are sent to European recycling plants for processing and then to be used to produce similar bags, and also industrial parts such as bush rings or rim bands. The material from small fertilizer bags and the inner bags of bulk bags made of PE is recycled to make wrap films and plastic bags (Ala-Siurua 2025).

Table 1. Different agro-plastic materials and their recycling options based on literature

Plastic material	Processing options	End-product categories	Bottlenecks
HDPE: - Shades, protective nets - Support ties & clips used in horticulture - The outer film in (double layer) clamp sheets - Bottles, containers & other packaging e.g. plant protectants, lubricants - Driplines, irrigation tubes - Nursery pots	Mechanical recycling to granulates HDPE can be worked by injection moulding, mould blasting, extrusion, membrane blowing and rotation moulding	- Same agro-plastic products (with virgin plastics) - Packaging materials e.g., bottles, canisters, crates - Components - Pipes, cable & wire coverings - Consumer products - Cargo pallets	Traces of harmful substances may prevent recycling plant protectant containers. If they are not properly rinsed, they are considered as hazardous waste.
LDPE: - Mulch film - Clamp sheets - Internal bags inside big fertilizer bags	Mechanical recycling to granulates LDPE is suitable for membrane blowing and extrusion	- Similar films	Mulch films are often dirty due to long soil contact
L-LDPE: - Bale wrap film - Silage tube film	Mechanical recycling to granulates	- Agro-plastic film (combined with virgin plastic as a layer) - Flexible packaging materials - Components - Consumer products (with injection molding) - Irrigation pipes	
PLA, PHA: biodegradable mulch films	Biodegradable (non-recyclable)		
PP: - Nets, ropes, lines - Bulk bags; outer bags in fertilizer bags **Horticultural (non-woven) fleeces** (also made of PE)	Mechanical recycling to granulates PP suitable both for injection molding as well as a wide range of extrusion applications	- Same products: ropes, lines, bulk bags - Fibres, profiles - Industrial parts	
PVC: Irrigation tubes, tarpaulin	Toxic material: processed as hazardous waste	Potentially recyclable by chemical recycling back to raw materials	

Own compilation by Yliskylä-Peuralahti based on Cirplus (2023a & 2023b), Clean Plastic Finland 2024, FAO (2021), Plastic Expert (sine annum), Plastic Recyclers Europe & ICIS (2023), Lewandowski & Skórczewska (2022), and information received from interviews conducted in 2024.

3 The recycling of agricultural plastic waste in Finland

Agricultural and horticultural plastic waste generated on a farm or in a greenhouse is regarded as industrial waste, and thus it is not accepted to municipal waste collection system. The responsibility of handling and storing the waste is solely at the entrepreneur itself, so that the surrounding nature is not harmed by this waste either. To fulfill this objective, the plastic waste generated on the farms and in greenhouses should be stored and handled appropriately, and then delivered regularly to a waste collecting point receiving this kind of waste for further processing (Finnish Waste Act 646/2011, 28§). This concerns such plastic waste which is not counted as packaging material of a production factor, which already has an existing free-of-charge collecting system in Finland through extended producer responsibility legislation (Government Decree on Packaging and Packaging Waste 1029/2021). There are many ways to solve the problem of plastic waste generated in primary production. The selected solution is commonly defined by the quality of the plastic waste, the nature of operations of the agricultural or horticultural entrepreneur and the location of the farm in relation to waste collecting points. Typically, entrepreneurs can handle the transportation of their plastic waste either by themselves or they can order a direct on-demand collection and transport from the farm, or they can subscribe a recurring collecting service with the local waste management company. Different solutions have different price tags attached, which also has a great effect to the selected solution.

Commonly the plastic waste from farms has been delivered to the reception points of various regional waste processing companies as a combustible mixed waste, or in the worst case, it has been stored at the farms for years or even for decades. This is an offence against the prevailing environmental legislation, which guides companies in handling the generated production related waste in a proper way. Agricultural and horticultural plastic waste, when stored in nature for a long period of time, leads finally to microplastics, which then later spreads in the food chain.

Delivery of the agricultural and horticultural plastic waste to a waste reception point is not so tempting for a farmer because collecting points are commonly far away (near larger centers of population), and thus the distance for transporting the plastic waste can be long and expensive. In addition, the reception of the waste has also an acceptance or gate fee; both of these generate costs that could be challenging to cover for the entrepreneur. An exception to this is the previously mentioned plastic packaging of production factors, for which a free-of-charge collecting and recycling system has already been established due to legislation defining that the producers of these production factors have the responsibility for organizing the collecting system for the packaging materials they use. In Finland this is done by organization called Sumi Ltd. Packaging materials used in agriculture include big storage bags for seeds or fertilizers, and canisters for liquid materials such as pesticides. This material is accepted free of charge at SUMI's industrial plastic terminals if it is correctly source sorted. The recycling system of packaging materials is based on extended producer responsibility legislation (SUMI 2025).

In addition to costs, common challenges for agricultural and horticultural entrepreneurs are that they do not know how to handle and store the plastic waste properly, or they cannot find information about where to deliver the plastic waste generated in their agricultural or horticultural production activities (Pönni 2023). Commonly, agricultural or horticultural plastic waste is generated continuously during a year, although with slightly different cycles for different types of plastics. For example, hay or feed bale wrap plastic waste is generated on livestock farms practically every day, and the amount largely depends on the size of the farm. Large livestock farms can use up to thousands of feed bales per year, or up to 20 bales per day, for example. Though it is becoming more common to use either closed vertical or open horizontal silos, also known as clamps. Thus, the amount of plastic wrap film waste is expected to decrease by time. On the other hand, crop harvesting farms use horticultural fleece to protect their crops against early spring frost, and the disposed fleece waste is generated usually between April and October. The frequency of waste generation and the material itself have both an effect to the way how those are collected and handled in the recycling process, and how the material can be utilized when recycled.

An essential challenge for motivating farmers to handle properly the agricultural and horticultural plastic waste is primarily the pricing of both the reception of the plastic waste and the transportation of it. Commonly a metric ton-based fee is charged for the reception of the plastic waste, which can be an insurmountable cost item for farmers working in a tight financial situation. In addition to the reception fee, also the transportation cost a lot of money, depending on the distance to the nearest waste reception station and the amount of waste transported. This cost can be reduced if the transportation is taken care by the farmer itself, which does seldom happen, because very few farms have suitable cargo vehicles for road transportation. Farmers could also seek for cooperation in organizing the collecting services so that the amount transported is maximized and thus the cost is shared among participating farms. Cooperation is crucial especially for farms located in remote locations.

When the agricultural or horticultural plastic waste from farms is delivered to the industrial waste handling stations, it is commonly handled as burnable mixed waste instead of recyclable material. The reception of waste can cost even 200 euros per metric-ton (including 25.5% of VAT). Together with transportation, the total invoice can be several thousand euros per delivery. On the contrary to this, some farms (usually located very remotely) store their plastic waste outside on the farm in large piles for years, sometimes even for decades. In such case, the plastic waste, which has fallen into the mercy of the weather and sun, is no longer suitable for anything else than burning it in a heating plant for energy production, in large scale boilers with a sufficiently high temperature. From time to time, agricultural plastic waste is also illegally burned at the farm or buried in the ground on the farm's own land, so that the plastic waste problem on the farm does not become visibly too large. Because this kind of behavior is illegal and needs to be avoided, the plastic waste material needs either be recycled whenever it is possible and reasonable, or then collected for burning in the heating plant. So, there are options available for handling the agricultural and horticultural plastic waste properly. Following companies are currently collecting and refining agricultural and horticultural plastic waste in Finland.

3.1 Suomen Maatalousmuovien Kierrätys Oy

Due to large amounts of plastic used in agriculture, there is a great need for a permanent, affordable collection and recycling system covering the whole Finland. Several attempts to create such a system has been done but unfortunately many of them were only short-lived. As a response to this need for collecting and recycling services in Finland, a national level collection and recycling scheme was set up in 2023 by a non-profit company called Suomen Maatalousmuovien Kierrätys Oy (SuMaKi). This direct on-demand collecting of agricultural plastic waste from farms started later in 2024. Suomen Maatalousmuovien Kierrätys Oy (SuMaKi) is a daughter company of the Extended Producer Responsibility (EPR) organisation for industrial plastics (SUMI Oy) and its members are companies who either manufacture or sell (as a subsidiary) agricultural plastic products in Finland. This means that the voluntary corporate responsibility for collecting and recycling the agricultural and horticultural plastic waste has been activated on this field as well.

The new system introduced by SuMaKi started in August 2024 by collecting plastic wrap film waste directly from farms. Farmers can order a pick-up for their plastic waste via an online application called ZeroWaste (Enpros). Agricultural film waste is most suitable for recycling because it generates a fairly stable waste stream and the quality of waste is fairly good when stored properly at the farms. See sorting guidelines behind following link: https://maatalousmuovienkierratys.fi/lajitteluohjeet/. The terms for agro-plastic waste collection can be found behind the following link: https://maatalousmuovienkierratys.fi/etusivu/noutotilausehdot/

SuMaKi forms a sufficiently comprehensive collecting and recycling system, divided to regions and operated almost everywhere in Finland, farthest places located in Lapland. Plastics from archipelago areas are collected separately, because these regions are challenging to reach and require a specific approach due to ferries (Interview with Mika Surakka and Anders Lundin October 17th, 2024). Direct collecting of plastic waste from farms for recycling works best when the waste is fairly "fresh" and the waste stream is relatively constant. Thus, another question is that how the old and dirty agricultural and horticultural plastic waste should be handled when it is not suitable for recycling?

3.2 Itä-Suomen Murskauskeskus

Before SuMaKi's new nationwide collecting system was established, there were some regional agricultural and horticultural plastic waste reception and collecting systems. A nationwide collecting service (subject to a payment) for agricultural and horticultural plastic waste was earlier available by Fortum Waste Solutions Ltd (Erälinna & Järvenpää 2019), but it ended in August 2019. Thereafter, a joint collection organized by MTK and Itä-Suomen Murskauskeskus has collected both recyclable and non-recyclable agro-plastics as a chargeable service since late 2019 (Maa- ja metsätaloustuottajien Keskusliitto MTK 2020). This paid service still exists and accepts non-recyclable agro-plastics. Itä-Suomen Murskauskeskus Oy (ISMK) is located in Joensuu, Eastern Finland and belongs to a consolidated company called Fluo together with five other waste handling companies (Fluo Group 2023). ISMK currently acts as one of the service providers for SuMaKi. Before the bankruptcy that stopped the operations of Clean Plastic Finland in July 2025, ISMK collected recyclable plastic waste and delivered it to Clean Plastic Finland Oy (CPF) in Merikarvia, where it was mechanically processed into recycled raw material (recycled plastic granulates).

In addition to agricultural plastic waste, ISMK also collects several other recyclable materials, such as industrial plastic waste, demolition waste, electronics waste, glass, metals and cardboard. Itä-Suomen Murskauskeskus Oy is also closely connected to software development company called Enpros Oy, which has been one of the pioneers in software development to provide a transport planning and logistics management system for waste management sector. The ordering system is called ZeroWaste (Enpros 2025), and it is used by several companies on the branch, including SuMaKi.

3.3 Sumi Oy

Sumi Oy (known before as Suomen Uusiomuovi Oy) is an extended producer responsibility (EPR) organization for industrial packaging plastics, which are used by any industrial manufacturer or producer who uses plastic packaging for their products, either packed in Finland or imported to Finland. Sumi Oy was founded in 1992 and it is a non-profit limited liability company owned by 33-member companies and organizations. Sumi Oy is also the mother company for Suomen Maatalousmuovien Kierrätys SuMaKi Oy. Sumi Oy has around 4000 industrial and business clients whose producer responsibility of packaging materials it takes care of.

The client companies of Sumi Oy, who package and import packaged products in Finland, have to take care of the whole life cycle of their packages, i.e. including following: collection, recycling, reporting and information related to their packaging material. The extended producer responsibility organization Sumi Oy handles these obligations centrally on behalf of the producers that have joined the community. When recycled, plastic raw material from plastic packaging can be used to manufacture a variety of new plastic products. According to Sumi, when compared using one kilo of virgin plastic material to using instead one kilo of recycled plastic material, using recycled material reduces 1.5 kilos of carbon dioxide (CO^2) emissions.

3.4 Salon Hyötykäyttö Oy

Salon Hyötykäyttö Oy is an active regional waste management company located in the city of Salo in Southwestern Finland. They receive a diversified selection of waste materials for recycling both from households and industrial sources, including also agricultural and horticultural plastics. They are one of the reception terminals for these materials based on extended producer responsibility (EPR). Their operative activities cover the land area in city of Salo for most of the waste materials, and they also collect and transport municipal household waste for further processing. Salon Hyötykäyttö Oy is also specialized in processing of the collected recyclable waste, meaning mainly sorting of collected waste fragments or preliminary crushing of those for energy recovery, and they aim to recycle all of the waste either as a fuel to burning facilities for energy production or to other industrial companies as a recycled raw material.

3.5 Hyötykeräys Oy

Hyötykeräys Oy (previously known as Vammalan Hyötykeräys Oy) is also a regional waste management company (located in Sastamala in Pirkanmaa), which receives a diversified selection of waste materials for recycling, including also packaging plastics already under producer responsibility (www.hyotykerays.fi). They accept clear plastic film from industries for recycling, but not agricultural and horticultural plastic waste. Their operative area covers the Regions of Pirkanmaa and Satakunta. In addition to the recyclable waste materials, they also collect and handle municipal household waste going for energy recovery (non-recyclable materials and hazardous wastes). Hyötykeräys Oy does some pre-handling of collected plastic waste, so that transportation is more convenient.

3.6 Lakeuden ympäristöhuolto Oy

Lakeuden ympäristöhuolto Oy (www.lyoy.fi) is a regional waste management company (located in Seinäjoki in Ostrobothnia), which also receives a diversified selection of waste materials for recycling, including also packaging plastics already under extended producer responsibility. They accept clear plastic film from industries for recycling and also agricultural plastic waste. Lakeuden ympäristöhuolto Oy has specialized in waste transportation, waste material sorting and processing, recycling, energy product manufacturing and information security services. Lakeuden ympäristöhuolto Oy has been operating in the recycling industry for 38 years. Their operative area covers the Regions of Southern and Central Ostrobothnia. Plastic waste materials are delivered to Clean Plastic Finland Oy, a granulation facility at Merikarvia.

Lakeuden ympäristöhuolto Oy has a goal to reuse all waste material from businesses. The principle is that all waste material is used primarily as a raw material and secondarily as a fuel in energy production. After sorting, approximately 64 per cent of waste materials go to recycling, 28 per cent to energy production, 7.5 per cent to other uses and only 0.5 per cent to landfill.

3.7 Clean Plastic Finland Oy

Clean Plastic Finland Oy (www.cleanplastic.fi) was a recycling and granulation company located in Merikarvia, in the west coast of Finland near the city of Pori. However, due to difficult market situation for granulates and heavy investment debts the company ended up in bankruptcy in July, 2025 (Tuomi 2025). CPF was the only company in Finland that was processing haybale wraps mechanically into recycled raw material (recycled plastic granulates) to be used again to make similar wrap films. Clean Plastic Finland Oy was founded in 2018 and its granulation plant started operating in 2020. CPF had co-operative agreements with SuMaKi, Itä-Suomen murskauskeskus Oy, Lakeuden ympäristöhuolto Oy, EkoRosk Oy and Kumeko Oy for collecting and delivering the agricultural plastic waste to CPF.

Figure 12. Crushed agricultural plastic waste fed to the granulation process (Veijo Pönni, 2024)

Lassila & Tikanoja, which has a recycling plant for industrial plastics close to CPF, plans to continue production in CPF’s facilities. They have applied for an environmental permit with 20 000 tonnes production capacity to run the acquired unit (Uusiouutiset 2026).

4 The results of recycling tests

LAB UAS tested the mechanical recycling potential of five agro-plastic samples. The testing focused on the necessary and upscaleable pre-treatment steps and processes to reach a commercially viable recyclate quality, and the performance was verified via thermal analysis and mechanical testing. The testing included the following five materials:

- Cucumber support twines and clips
- Mulch films (from a strawberry farm)
- Horticultural fleece
- Straw bale netting
- Irrigation hoses

Important initial analysis comprised material identification, since no clear markings were included in the samples indicating the polymer grades. While the commercial identification and sorting tend to utilise NIR spectroscopy, FTIR was used to ensure accurate identification in lab scale. It should be noted that both the mulch film and irrigation hose material are black, which affects especially rapid NIR identification negatively. Figure 13 presents the results of material identification.

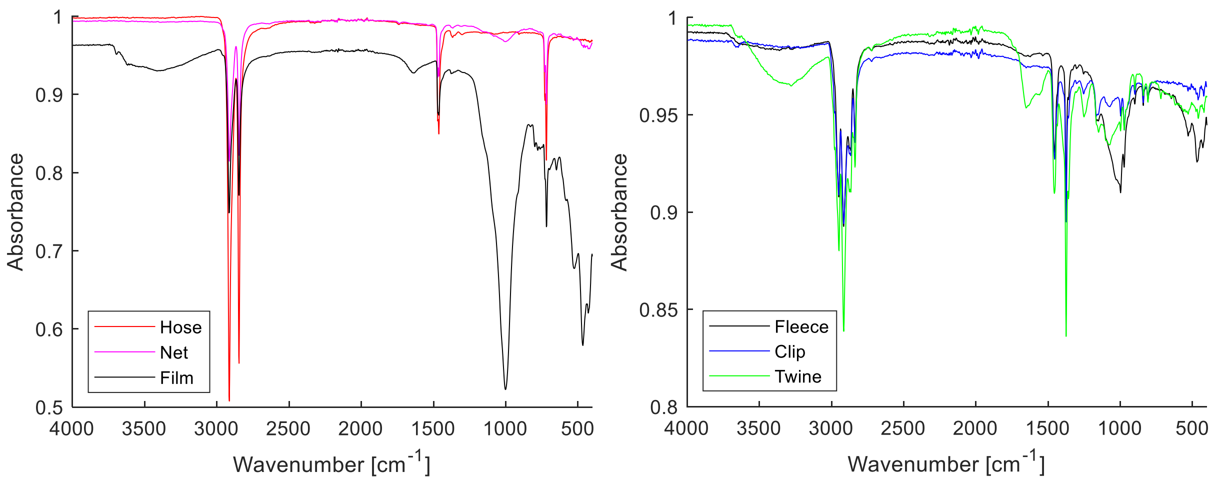

Figure 13. FTIR spectra for samples identified as PE (left) and PP (right).

The most significant challenge for recycling the agro-plastics is the handling and pre-treatment of the material to reach a suitable material purity and particle size. Impurities and contaminants are largely sample dependent with soil-based impurities such as dirt dominating the mulch film, horticultural fleece and irrigation hose samples, whereas the cucumber twines and bale netting contain large amounts of agricultural product residues, namely cucumber stems and straw, respectively. The dirty samples are generally well suited for a standard recycling process, where the pre-treatments comprise particle size reduction followed by washing and finally processing into recycled material.

For the plant-based solid contaminants (cucumber stem and straw), a separation process is needed. The cucumber stems were noted to dry and embrittle when stored in standard atmospheric conditions quickly, after which mechanical agitation is sufficient to break down the stems and separate them from the plastic. A similar approach is, however, not feasible for the straw bale netting. The straw remains ductile even when dried and the strong, thin fibrous nature of both the plastic and the plant matter disqualifies all common size reduction methods. The key enabler for pre-treatment was a thermal compacting process, performed with a single screw extruder. A commercial, robust and upscaleable process could be established based on, for example, the VTT MODIX concept (Kaya & Javanshour 2024) or similar. Flotation/density-based separation was tested in a small batch scale in the laboratory and showed that most of the straw can be separated easily, as shown in Figure 14 presenting the laboratory scale proof-of-concept trials. The separation trial resulted in two material fractions, the exclusively straw fraction (2.937 ± 0.005 g, ~5.3%) and the plastic rich fraction (52.4 ± 0.1 g, ~94.7%). The reported masses indicate dry mass of each fraction with errors corresponding to a combined error estimation of the material recovery and the measurement. The purity of the plastic rich fraction is already suitable for lower quality recyclates and could be further improved with reduction to smaller particle size or additional separation steps in the pre-treatment.

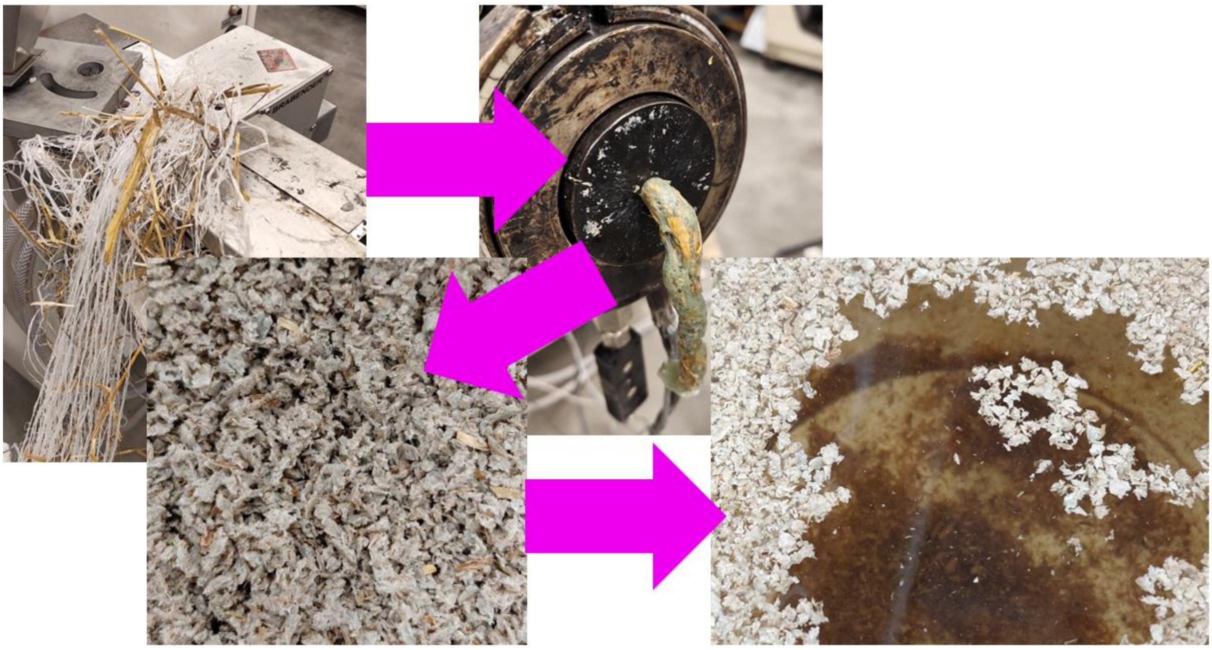

Figure 14. Straw bale netting compacting process and the final crushed material. Minimal mixing during the compacting process allows the straw particles to separate from the plastic.

The crushed plastics were then washed. To enhance the separation of the dirt-like surface contaminations, a combination of water rinsing, frictional force and centrifugal agitation was utilised for the washing process. A similar process, called friction washing, is an established state-of-the-art option for plastics recycling (Mager et al. 2026) and known for effective separation of surface dirt and other such contaminants. The process was especially effective for the mulch film, irrigation hose and horticultural fleece samples. After drying the resulting materials are ready for recycling. It is worth noting that a very high moisture content remained trapped in the porous, high surface to volume ratio fleece material and effective heated dry-air drying process and effective venting of the recycling extrusion process are recommended.

After washing the plastic materials are ready for compounding into recycled materials. Differential scanning calorimetry (DSC) was utilised to evaluate the degradation, thermal stability and suitable processing conditions for each material. Since the materials are already identified as polyolefins, a temperature range of -35 °C to 250 °C was measured, using two heating cycles per sample. Significant changes in the melting enthalpy between the first and second heating cycles are used as the primary indicator for ageing or degradation, while the second heating results are used for processability and thermal stability evaluation. Table 2 presents the key observations made based on analysing the DSC results.

Table 2. Analysis of the DSC results

Sample	Melting temp. [°C]	Thermal stability [-/+/++]	Recom. process temp. [°C]	Degradation [--/-/+]
Cucumber twine	Onset: 150 °C Peak: 160 °C	Poor [-]	180-190 °C	Minor [-]
Cucumber clip	Onset: 145 °C Peak: 165 °C	Poor [-]	180-190 °C	None [+]
Mulch film	Onset: 115 °C Peak: 124 °C	Excellent [++]	160-190 °C	None [+]
Fleece	Onset: 153 °C Peak: 161 °C	Poor [-]	180-200 °C	Notable [--]
Bale netting	Onset: 115 °C Peak: 132 °C	Decent [+]	160-190 °C	Minor [-]
Compacted netting	Onset: 109 °C Peak: 133 °C	Decent [+]	160-190 °C	None [+]
Hose	Onset: 102 °C Peak: 126 °C	Decent [+]	160-190 °C	None [+]

The DSC results offer further insights into the material identification. For example, while the cucumber twine and clip are both further verified as PP, their melting behaviours differ significantly, indicating different PP grades. For an effective industrial scale recycling, the grades should be compounded into a single recycled grade since separating the twines and clips in scale is both technically challenging and economically infeasible. The grades also exhibited quite poor thermal stability, observed as non-linearity in the DSC baseline starting already below 200 °C. The recycled plastic should therefore be restabilised with additives. Similar observations are made for the horticultural fleece, which is also the only material to exhibit indications of any notable in-use degradation. Some minor change in the melting behaviour was also noted for the cucumber twine and bale netting, which are also expected to withstand significant UV-exposure during use. However, the changes are minor enough to be considered uncertain. Based on the DSC results (and use case) the mulch film and irrigation hose materials are from very similar grades of PE and can be combined for recycling. To evaluate this potential for the cucumber twine and clips, capillary rheometer measurements were used to measure the melt flow behaviour in the 10 – 3000 1/s shear rate range at 190 °C. The measurements utilised a zero-length capillary die to estimate the Bagley correction and the shear rates were adjusted with Weissenberg-Rabinowitch correction to acknowledge the non-Newtonian flow behaviour. The results are presented in Figure 15.

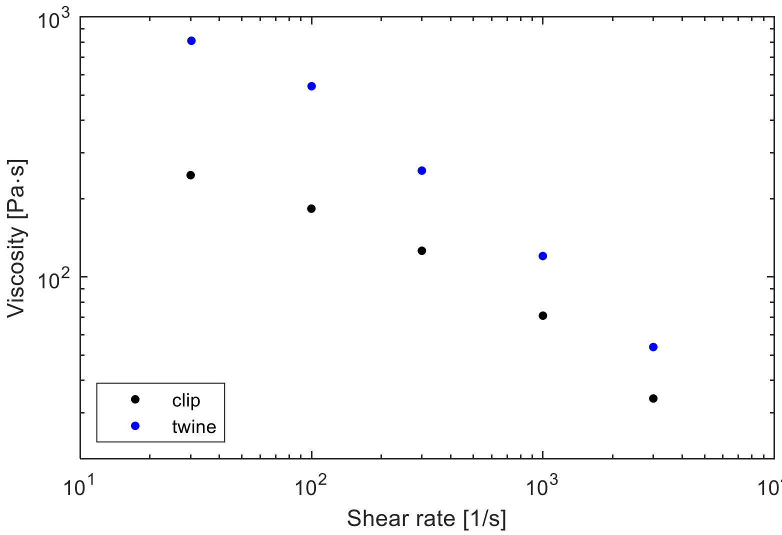

Figure 15. Double logarithmic flow curves for the cucumber twine and clip PP materials.

The flow curves indicate very different PP grades and flow behaviour. This result was expected based on the very different use-cases. The thin fibrous twine and 3D-shaped clip were expected to be manufactured from fibre extrusion and injection moulding grade materials, respectively, which is validated by the flow curves. The most economically effective recycling process would therefore include a tailored formulation of mixing the grades and using additives, such as peroxides (Azizi et al. 2008) or chain extenders (Barros et al. 2026), for molecular weight modifications to control the rheological properties of the recycled plastic. Both additives are commercially available for this purpose. Unfortunately, the material volumes available for the trials was insufficient for pilot scale testing of the final compound.

The final stage of the material validation for recycling is mechanical testing of the plastic grades. The testing utilised an ISO 527-1 standard tensile test utilising a Lloyd universal testing setup with a 2.5 kN load cell. Deformation rate was set to 10 mm/min as per the standard with 5 specimens tested for each material sample excluding the cucumber support twine and clips, for which the amount of material ran out before tensile specimens could be manufactured. Average tensile properties for each plastic are presented in Table 3. For the horticultural fleece – noted during pre-treatment trials as difficult to handle and process – as received samples manufactured by directly feeding the fleece into the injection moulding machine were also tested for comparison. The added tests indicated significant degradation of the material during the pre-treatment leading to increased ductility and reduced stiffness of the material, which limits the applicability of the material in similar applications to the original but enables new alternatives.

Table 3. Mechanical properties of the EoL agro-plastics.

Sample	Modulus [MPa]	Yield strength/ Tensile strength	Stress at Break [MPa]	Strain at Break [mm/mm]	Notes
Cucumber twine	--	--	--	--	No samples tested
Cucumber clip	--	--	--	--	No samples tested
Mulch film	226 ± 44	13.3 ± 0.8	14.8 ± 0.8	3.10 ± 0.43	
Fleece (as received)	990 ± 36	28.5 ± 6.3	28.5 ± 6.3	1.00 ± 2.10	4/5 exhibited brittle failure with < 10% strain.
Fleece	670 ± 119	28.4 ± 0.58	25.1 ± 4.9	1.51 ± 2.13	3/5 exhibited brittle failure with < 10% strain.
Bale netting	265 ± 50	13.0 ± 0.25	14.2 ± 0.5	4.17 ± 0.65	
Hose	267 ± 79	16.0 ± 0.5	14.6 ± 0.7	4.36 ± 0.13	

In summary, all tested materials can be considered viable for mechanical recycling. Most have specific limitations that need to be mitigated in the pre-treatment stage of the recycling process or the actual recycling stage, for which state-of-the-art processes were tested and assessed as suitable. The main limitation for practical implementation is therefore the economic viability, investment willingness of recyclers and waste managers, and ultimately uptake of the recycled materials by agricultural actors or other end users. Evaluating these aspects in the current Finnish operational environment is, however, outside the scope of this chapter.

5 Chemical and ecotoxicological analysis results

5.1 Chemical analysis results

Syke laboratory conducted chemical analysis and bioassays for agro-plastic samples collected from farms in the autumn 2023 (as a part of work conducted in PlastLIFE Work Package 3). The following materials were tested:

- cucumber support twines and clips
- cover films of cucumber growth bags (classified as agricultural packaging plastic)
- mulch films (from a strawberry farm)
- horticultural fleece
- haybale wraps (a sample collected by Karelia UAS)

The substances to be analysed in chemical analysis were prioritized based on their harmfulness, usage and based on the need for further information, e.g., in the implementation of the legislation. The main focus of the analyses was to verify whether the materials contained harmful substances that must be removed from the recycling streams. Therefore, the analyses were directed to certain heavy metals (Cr, Ni, Cu, Zn, As, Cd, Hg ja Pb) (Table 4) and relevant persistent organic pollutants including phtalates (19 different chemical compounds) (Table 5), and bentzotriazole derivates (8 chemical compounds) which are used in plastic products as protection agents against ultraviolet light (UV). All samples were processed to small particles or fine powder for chemical analyses.

Table 4. The analysis results for heavy metals

Chemical element	The range in concentration levels	Plastic sample with highest content
Chromium (Cr)	1 – 630 mg/kg	Horticultural fleece
Nickel (Ni)	0.5 – 317 mg/kg	Horticultural fleece
Copper (Cu)	0.4 – 25 mg/kg	Horticultural fleece
Zinc (Zn)	2.5 – 78 mg/kg	Mulch
Arsenic (As)	0.06 – 0.4 mg/kg	
Cadmium (Cd)	0.04 – 0.2 mg/kg	
Mercury (Hg)	0.01 – 0.2 mg/kg	
Lead (Pb)	0.03 – 3.1 mg/kg	

Data: Timo Sara-Aho/Syke (2026)

Heavy metals with highest concentrations were zinc (Zn), chromium (Cr), nickel (Ni) and copper (Cu). Although traces of other heavy metals were found in all analysed samples, the amounts are not high and do not prevent recycling of the plastic materials (Table 4).

Table 5. The analysis results for phtalates

Chemical element	The range in concentration levels	Plastic sample with highest content
Dibutylphthalate (CAS 84-74-2)	0.025 – 1.73 mg/kg	Horticultural fleece
Bis(2-ethylhexyl) phthalate (CAS 117-81-7)	0.17 – 3.5 mg/kg	Mulch film

Data: Hanna Niemikoski/Syke (2026)

Phtalates, especially Dibutylphthalate (CAS 84-74-2) and Bis(2-ethylhexyl) phthalate (CAS 117-81-7) were found in all analysed samples, but the concentrations are not high and are below limit values (Table 5.). In addition, low concentrations of Diisobutyl phthalate and Bis(2-ethylhexyl)terephthalate were found in some of the samples.

No significant amounts of UV protection agents were found.

5.2 Bioassays

Bioassays are tools that complement chemical analyses in environmental risk assessment. Bioassays can reveal presence of unknown substances, and if detected with tests with certain mode of toxic action, can guide the analysis towards specific chemical groups (e.g. herbicides, genotoxic compounds). Moreover, bioassays integrate the effects of mixtures, can support regulatory use and serve as an early warning sign. To construct a framework for analysing recycling potential of agro-plastic waste from the point of view of chemical risks, Syke selected three types of bioassays commonly applied in vivo tests: inhibition of light production in bacteria (*Aliivibrio fischeri*), earthworm (*Eisenia andrei*) reproduction and in vitro tests able to measure genotoxicity.

Test method for *A. fischeri* and in vitro tests was liquid extraction with water: shred agro-plastic samples were mixed in water for 7 days, and thereafter bioassays were applied for the water phase. The test conditions simulate environmental harm caused to living organisms by water-soluble substances released from plastics. For earthworm test, two mulching film samples were tested: one from conventional farming where plant protection products had been used and one from an organic farm. These materials were tested by mixing ground mulching film material in Lufa 2.2 standard soil.

Genotoxicity or inhibition of light production of bacteria was not found in any of the tested water extracts. Limit of detection (LOD) value for oestrogen equivalents (E2, estradiol) was exceeded in two of the tested mulch film samples. The presence of unknown chemicals with estrogenic potential was, therefore, too low for estimation of E2 equivalent concentrations. Number of juveniles produced by earthworms was not affected by either of the tested mulching film materials.

6 Future recycling options for agricultural plastic waste

Agricultural plastic waste management in Finland could benefit significantly from various potential recycling strategies, informed by practices and emerging technologies. Mechanical recycling remains a viable method for agricultural plastics, particularly for polyethylene (PE) and polypropylene (PP) materials, which are commonly used in agricultural applications. Chemical recycling presents a promising alternative for managing contaminated or mixed agricultural plastics that pose challenges to mechanical recycling. Polyethylene, polypropylene and polystyrene, which are prevalent in agricultural applications, possess high calorific value suitable for energy production through chemical processes such as pyrolysis (Shanker et al., 2022).

Figure 16. Machinery and equipment used within the CPF recycling facility. (Aaqib Mohammad, 2024)

The recycling process for the production of pellets involves several stages, beginning with pre-treatment, followed by shredding, multiple washings of the dry shredded waste, final drying using a fluidized bed, and ultimately, conversion into pellets through an extrusion process. The initial stage, known as pre-handling, typically employs a mobile shredder (Tana) to prepare and process agricultural plastic waste, such as bale wraps, mulch films, and irrigation pipes. This pre-handling step is crucial for rendering the agricultural plastic waste more manageable, thereby enhancing the recycling rate by reducing the volume of waste. The CPF facility that previously recycled agricultural plastics, was equipped with an inbuilt mobile shredder that operated fully within the premises, thereby mitigating potential spillage risks. The primary objective of shredding is to fragment the plastic into smaller pieces, facilitating subsequent processing. Mechanical recycling constitutes an essential element of the future strategy for advancing a circular economy, necessitating solutions to enhance market viability ("TEPPFA Position Paper on Circular Economy," 2025).

The future goals for recycling agricultural plastics will be monitoring the plastic waste on farms by mapping out the amount of generation of agro-plastics, enhancing guidelines for handling the waste through farm waste management system and finally development of new methods for the collection and recycling agro-plastics.

More essential challenge for improving the recycling of agricultural and horticultural plastic waste is to answer the question how to organize a nationwide cost-effective collecting system of these waste materials, to get the waste streams for further processing of recycling. Current system built by SuMaKi is a good start, but it does not cover the whole spectrum of available plastic waste. Professional agricultural and horticultural activities are spread more wider than what the collecting system covers, even in very remote locations. The long distances from farms to plastic recycling plants creates a logistic challenge.

6.1 Guidelines for sorting and storing agricultural plastic waste on farms

A key challenge on farms is how to handle the plastics so that they remain recyclable. Recyclable plastic must not be too old, almost clean, of the same quality and stored well protected from the weather. The requirements for cleanliness are so strict that mulch is not suitable for recycling, as it is often in contact with the ground during the growing season, at least at its edges. Plastic waste should also be delivered for recycling at a relatively high frequency, so that the quantities transported remain manageable and a regular "feed stream" is created for the recycling system. If the above conditions are not met, the dirty plastic waste accumulated on farms ends up either in waste stations as burnable/energy waste or, through separate collections, also in incineration plants and thus become part of energy production. This option in itself is not so bad, as plastic waste that is not suitable for recycling is removed from nature and can be utilized in energy production, as plastics are, after all, crude oil-based products.

Many different instructions have been drawn up for the storage and handling of plastic waste on farms (see e.g. Hytönen 2024). The most important thing is that plastic waste should be sorted according to plastic quality and packed as compactly as possible for transport. For example, discarded tarpaulins should be collected around a wooden stake in a tight roll, which is then closed with string or tape. This way, the rolls will not open and spread when they are handled during transport. Baled plastic waste, on the other hand, should be collected together and pressed into small bales, which can then be handled, for example, with a telehandler. At some point during the delivery of agricultural plastic waste, either for recycling or to an incineration plant, the plastics are handled by a crane with some kind of grapple, for example a log grapple or an onion grapple. In this case, well-packed plastic waste is easier to handle, and there will be no significant delay in its handling. Regarding storage, it should be ensured that the plastic waste is protected from the weather, which will keep it cleaner and better suited for recycling.

Figure 17. Well-collected and stored horticultural fleece / gauze (Veijo Pönni, 2022)

When storing indoors, fire safety regulations must also be taken into account, as plastic waste significantly adds to the fire load of a building and therefore it must not be stored indoors in large quantities. It is also important to ensure that the recyclable plastic waste does not contain anything that does not belong there. So-called “mixed loads” should be avoided. Smaller quantities of agricultural plastics can be disposed of with combustible mixed waste.

Figure 18. Self-made press to package bale wrap plastic waste. (Leena Erälinna, 2019)

Figure 19. A bunch of tight packed bale wrap plastic waste (Leena Erälinna, 2019)

On some farms, plastic waste is collected, for example, in old small waste exchange pallets with lids, the size of which is, for example, approximately 10 m^3 (Figure 18). The emptying of the waste container is handled either by an external transport company or with the company's own transport equipment as needed. The plastic bales remain well protected from the weather in the waste container.

Figure 20. Approximately 10 m^3 interchangeable waste container (Veijo Pönni, 2022)

Figure 21. Dirty bale wrap waste in the interchangeable waste container (Veijo Pönni, 2022)

Disused gauze rolls and baled plastic waste can also be collected in a low, open pallet, which is then emptied as needed. This also requires a tarpaulin to protect the plastic waste from the weather. Such a pallet can be purchased for shared use by several farms or by a local potato cooperative.

7 Conclusions

Many types of plastic materials are used in agriculture and horticulture sectors to enable and enhance production operations. Plastics have been used on farms and in green houses for several decades and have become an established part of the production operations. Investments have been made in relevant machinery which use plastic materials, for example a hay bale wrapper at a farm or a planting machine in a greenhouse. The most typical agricultural plastics are stretch films used to protect feed bales and fleece/gauze used as frost protection in crop cultivation, for example. The volumes of plastic waste generated from these usages are large: approximately 9 000 tonnes of haybale wraps are put to markets in Finland every year (Suomen Maatalousmuovien Kierrätys 2024). Of course, many other types of plastics are also used in agriculture and horticulture, such as canisters for packaging plant protection products and big bags for delivering seeds and fertilizers. Of these, big bags in particular have been recycled for a long time, already for 50 years thanks to 4H activities. In addition, certain agriculture activity such as strawberry farming uses irrigation piping to ensure that plants get enough water. At some point of time these plastic pipes become also waste. However, there is no viable, widespread and strongly established recycling system for these kinds of plastic products other than the aforementioned big bags, even though there is a clear need for one. Most recent attempt by SuMaKi for collecting wrap film waste seems very promising, and time will show how successful it is. While recycling tests as well as chemical and toxicological analysis conducted for other materials which are not yet collected for recycling in Finland (including haybale nets, horticultural fleece, mulch films, horticultural twines and clips, and irrigation hoses) show that these materials are suitable for mechanical recycling, most agroplastic materials have specific limitations that need to be mitigated either in the pre-treatment stage of the recycling process or in the actual recycling stage, for which state-of-the-art processes were tested and assessed as suitable. The main limitation for practical implementation is therefore the economic viability, investment willingness of recyclers and waste managers, and ultimately uptake of the recycled materials by agricultural actors or other end users. To increase recycling of agro-plastics, the whole value chain of recycling has to function properly and efficiently, so that the end user of recycled plastic granulates, the plastic industry itself, accepts the recycled material in its production.

The farms commonly face some problems in sorting and storing the plastic waste. A typical sight on farms is that all possible plastic waste has been collected in a slowly growing stack, usually outside because the farmer does not know what to do with it. As storing waste for a long time is illegal, these outdoor stacks often are hidden in remote places on the farm where other people would not see the huge piles of plastic waste. These stacks may be in very difficult locations that are even inaccessible for the waste collection vehicle. When the waste stacking has continued for long periods of time without any concrete plan for delivering the plastic waste away, the farmers have faced an overwhelming waste problem. Storing the plastic waste outdoors without any protection weakens the quality of plastic waste dramatically, because to be recyclable the plastic waste needs to be dry and clean, and fairly fresh. In addition, recyclable plastic waste should be unified material, so the different plastic materials should be sorted properly already at the farm or at the greenhouse. Otherwise, the plastic waste is suitable only for burning in an energy production facility.

In addition to the storing and collection issues, also the economic side of recycling plastic waste is challenging for farms and greenhouses due to the prevailing weak economic situation of the agricultural sector. The cost of receiving agricultural plastic waste is high due to the high costs of collecting and processing. When delivering plastic waste as combustible mixed waste to waste management stations in Southwest Finland, the cost of receiving could be even 200 euros per metric-ton (incl. VAT 25.5%). These prices were the prices valid at the time of collection in autumn 2022 and have risen since. Transport from very remote locations costs also a lot of money when the transport is bought from a company. The high collection costs encourage illegal storing and eradication of plastic waste e.g. by burning it.

For those farms that are located in the most remote areas and at difficult distances from existing or future collecting points, the most viable option is to cooperate in collecting and delivering their own agricultural plastic waste. These farms should establish a joint private collecting point in a location that is only accessible to farms participating in the collective delivery system. The collecting point can be, for example, a removable pallet covered with a tarpaulin. When the pallet is full, it can either be ordered separately or its transport to the nearest collection point can be arranged. Waste management companies can create their own customer base for such a collection point, within which a pre-agreed division is created for sharing the costs among the farms participating in the collection point. This way, agricultural plastic waste from even the most remote farms can be utilized either for recycling or for energy production in thermal power plants. If local producer cooperatives or similar groupings already exist, for example for carrying out joint procurement, such organizations can also act as a platform for cooperation by managing a common collection point for plastic waste.

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