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THE ROLE OF AGRICULTURE IN MARINE PLASTIC POLLUTION

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Abstract

The world consumption of plastics in agriculture amounts yearly to approximately 7.4 million tons and forecasts expect it to increase to 9.5 million tons in 2030, but this data is still limited. Conventional and selective polymers such as PE, PVC, EVA and nets are used to optimize crop production efficiency in the Mediterranean coast. The major drawback starts when the material has reached its useful time and is abandoned and dumped near dry river bed channels where it accumulates as it waits for runoff to wash them towards the sea. Since there is a lot of data missing on the amounts, composition and environmental fate, this research aims to fill the above mentioned substantial gap by performing a research on the Agriculture Plastic Waste life cycle and current management. Once the main issues were identified, a proposal for monitoring sources and fluxes was studied using Unmanned Aerial Vehicles (UAVs) imagery combined with GIS systems as a tool for plastic litter detection, and fluxes on hotspots as they represent a key source of plastic litter accumulation before it reaches the marine systems if actions are to be taken.

For the latter, imagery data acquired by UAVs and combined with *in situ* surveillance to detect mismanaged macroplastics location due to illegal dumping on dry riverbeds in Castell de Ferro, a town located in the tropical coast of Granada in Spain which is as famous for its tourism as for the plastic greenhouses. The study area, was considered suitable for these purposes because it involves a dry riverbed constantly impacted by APW dumped or abandoned by farmers nearby.

The image data acquired was then processed and validated with in situ identification of the macroplastics. As a result, the GIS tool was considered to deliver the necessary data for accurate plastic litter assessment and detection. This study was able to detect agriculture macro-plastics showing success performance over 95%. As for the management measures, producers must design and manufacture reusable and recyclable agriculture plastics. To further the process, economic and financial incentives on RDI programs on APW need to be developed in order to avoid or reduce to the extent hazardous substances use on plastic manufacture.

Key words: remote sensing, intensive farming, greenhouses, multispectral sensor, marine litter, agroplastic

1 Introduction

Agriculture can be defined as the art of producing goods and services from nature (Larrazabal, 2022). Traditionally, the development of agriculture has taken place in those areas where water and soil are available within optimum climatic conditions. Using the advantages in technology, the afore mentioned factors are not a limiting issue for production nowadays. Among these technological advances stands out, among others, the use of plastics.

The use of plastics in agriculture began in the 50s when the sector was facing problems such as lack of water and labor in addition to high costs of materials like glass and steel or concrete have added an important economic challenge and demanded to be competitive transforming apparently unproductive land into highly profitable farms (Plaine Products, 2022; Castilla, 2004; FAO, 2021). Today, the province of Almería located in Spain stands out as the largest concentration of greenhouses in the world, constituting an authentic "plastic sea" (Crumbie L. , 2021). Likewise, in that area as well as other places within the Mediterranean coast, are facing an important environmental issue. Among the main applications of plastics, we can mention crop protection through its use in padding, tunnels and greenhouses; or other applications such as irrigation distribution networks, raffia threads, large reservoirs, irrigation and drainage, shading nets or anti-hail, windbreaks, fodder silage, containers and packaging (Bláquez, 2003). Nowadays plastics are generated in large quantities and are varied in their composition or nature. While plastics in agriculture present several advantages increasing productivity and efficiency and help minimize food loss and waste in all agriculture sectors; on the other side, plastics are a major source of contamination in water bodies and soil, persisting in the environment long after their intended use, transferring and accumulating in food chains, threatening food security, food safety and potentially human health. (FAO, 2021). This circumstance contrasts with the fact that it is a subject marked by important shortcomings on its proper management lacking a global and contrasted vision often evident in numerous areas of the territory but still invisible to many. Therefore, it is not surprising that it has not been broadly studied, from the social, environmental and legal aspects, being very scarce the bibliography that addresses those issues (Dupuis, 2012).

For this reason, supporting actions towards the better management of APW in the so called *plasticulture* along its chain value fills a substantial gap in scientific research by improving the knowledge on the flows and fate of agricultural plastic products. Actions should address an urgent need to detect main gaps and issues on the current legal framework, management of agriculture plastics, track fluxes and monitor the large amounts of plastic products used in agriculture that leak into the environment (FAO, 2021). Secondly, the benefits and issues associated with major plastic products used in agriculture must assess alternatives and interventions to reduce their adverse impacts.

Because of conditions such as dispersed allocations of farms and plastic accumulations and often lack of resources intended for this issue, cost-effective solutions must be developed to identify and monitor litter hot spots along the territory as a tool for academic researchers and policy makers. Among the main actions taken to monitor plastic litter management is to locate dumped plastic accumulations using remote sensing. This aims to serve direct societal and environmental purposes: first, it will help farmers manage their plastic waste and secondly it will provide a new tool to mitigate plastic pollution to the environment. The aim of this tool is to reveal plastic sources, transport and distribution, and thus assist prioritized and cost-effective actions oriented to reduce and eliminate the plastic problem.

Promoting circular approaches is essential to reduce plastic generation, pollution and the indirect impacts of greenhouse gas emissions associated with the use of petroleum-derived plastics through prevention, reduction, reuse and recycling to achieving more efficient, inclusive, resilient and sustainable systems in order to deliver better production, nutrition, a better environment, and finally a better life quality.

1.1 Plastics and its use in agriculture production

1.1.1 Plastic materials used in agriculture and their benefits

Plastics are synthetic or semi-synthetic polymers designed to create a wide range of products that can be molded, extruded or pressed into rigid, semi-rigid, or flexible products with specific properties and/or additives depending upon its intended use (FAO, 2021).

Plastic use on agriculture is broad and diverse and its main purpose is to increase productivity and reduce food losses throughout the value chain. The use of plastics is among the measures for the application of Best Available Techniques in the selection of alternatives that United Nations Environment Program (UNEP) recommends in the Integrated Pest and Disease Control programs and Integrated Management of Crop Production, to reduce synthetic pesticides consumption and emissions, particularly in soil fumigation use, and physical alternatives to this type of treatment through soil solarization and mixed techniques of solarization and biofumigation (Barres Benlloch, 2007).

1.1.2 Crop efficiency

Conventional and biodegradable plastics are present in very diverse areas of agricultural protective coverage in the form of sheets, plates or different forms according to its use in horticultural, fruit, flower and ornamental crops management in intensive agricultural production, such as greenhouses, tunnels, padding and hydroponic cultivation, without conventional soil or in nutritive solutions, as well as in aeroponic cultivation (FAO, 2021; Barres Benlloch, 2007).

Among the main benefits brought by plastics in agriculture we can mention the increase in crop yields by reducing water demand (through the use of tubes and pipes for drip irrigation, or mulch films to prevent evaporation losses), optimizing germination from seeds (through seedling pots), reduce herbicide use (the use of mulch films prevent weed growth), extend growing season or protect crops from extreme temperatures (through greenhouses and tunnels), combining benefits reduce food losses, soil moisture, damage by animals, assist fermentation of grasses for animal fodder (through silage films), rely on nets, ropes and floats (in fishing), and maintains quality of fresh products (avoids damage), because of their lightweight packaging it also optimizes cost and fuel needed to transport products and finally delivers information to customers (through the use of labels and liners) (Castilla, 2004; FAO, 2021).

Figure 1. Cover film used for cucumber protection in Castell de Ferro.

Therefore, a protected crop is defined as a specialized agricultural system in which control of the environment is carried out by changing its conditions (soil, temperature, solar radiation, wind, humidity and atmospheric composition). Through these protection techniques, plants are cultivated by modifying their natural environment to extend the harvest period, alter conventional cycles, increase yield and improve their quality, stabilize production and avail products when outdoor production is limited (Castilla, 2004). Thus, as stated before the main objective is to improve efficiency by reducing wind speed, limit arid climate impacts and reduce diseases, damage from pests, water intake and protecting crops against low temperatures, nematodes, weeds, birds and other kind of predators (Castilla, 2004; Britannica, 2022). Since all plant species have an optimal range for each environmental parameter, placing a screen or protection alters the environmental conditions that affect the entire plant or a part of it. In this regard, the position of the screen or protection with respect to the plant determines the type of protection. When the plant is placed on the ground, plastic is set as padding, the windbreaks constitute screens or lateral protections; when the screens are placed over the plants as a cover, tunnel greenhouses and floating covers are obtained. In the following figures, plastic cover protects crops from adverse climatic conditions and improves use of resources (e.g. water and nutrient absorption efficiency) (Castilla, 2004).

Figure 2. Grapevine style greenhouse originated in Almería (Valverde & Montero, 2017)

Among its uses, the following can be highlighted: windbreak meshes, natural light, visible, infrared radiation and UV diffuser (photoselective plastics), photoperiodicity control in intensive agricultural production, including herbs and weeds elimination avoiding chemical use. Combined with metal stripes, they can also contribute in virus transmission prevention.

They are also found in the form of non-foamed plastic pieces in irrigation networks (pipes, valves, drippers, etc.), in polyethylene sheets (PE) or as waterproofing of reservoirs and cisterns, in pipes, drippers or in water recirculation systems for nutrient solutions, as well as in livestock, forage management, silage, and other diverse uses (FAO, 2021).

Plastics are also part of various supports and materials for the in vitro culture of meristems, donative propagation and other forms of propagation of healthy plant material (Barres Benlloch, 2007).

In the field of aquaculture, mention should be made of the use of plastics in fish farms and aquaculture facilities, in particular for the manufacture of rafts and ponds, trays and cages, containers, filters, feeding systems, etc. The material however is degraded through time by climatic agents such as wind, radiation and water among others. Once it has performed its purpose it is discarded as a waste which often is mismanaged (Barres Benlloch, 2007; FAO, 2021).

For the purposes of this research, the plastic waste used in agriculture will be called Agricultural Plastic Waste (hereinafter, APW).

1.1.3 Most used plastic films in greenhouses

The most common used materials are Polyethylene (PE) which can be either Low-Density Polyethylene (LDPE) or High-Density Polyethylene (HDPE), Polypropylene (PP), Polyvinylchloride (PVC), Polyethylene Terephthalate (PET), EVA and its derivatives, frequently incorporating several layers of different materials in multilayer films (Figure 3). There are less frequently used films such as Polycarbonate, Polymethylmethacrylate (PMMA), Thermoplastics Polyurethane (TPU), Polyamide (Nylon and Acrylonitrile Butadiene Styrene (ABS) (FAO, 2021 (Castilla, 2004)). They are used greenhouses used as a cover (in the case of plastic films), nursery pot trays, irrigation and drip tapes or pipes.

Biodegradable polymers are used now more frequently and we can mention Polylactic Acid (PLA), Polyhydroxyalkanoates (PHA), Polybutylene Succinate (PBS), Polybutylene Adipate Terephthalate (PBAT), Polycaprolactone (PCL) and starch blends. Films with special characteristics such as long duration films, termic films, antidrip films, multilayer films and photoselective films are used for specific purposes. For the purpose of this study, only normal plastics and photoselective films will be described.

Low-density polyethylene (LDPE) whose density is less than 0.93 kg*m-2 is usually used on greenhouses and is obtained by radical polymerization in high-pressure processes. Its transmissivity to solar radiation is good, its thermal behavior is mediocre, given its transparency at IR-long, if there is no condensation of water in the film. Incorporation of thermal additives solves this problem (Castilla, 2004). For life extension, additives that protect from the degrading action of UV rays are incorporated into the process in order to provide certain qualities or improve existing characteristics without affecting the molecular structure of the polymer. Additives can facilitate the transformation process or they can provide certain qualities to the plastic (functional), and can reach up to 10% of the final weight of the product (Diaz Serrano, 2001).

Figure 3. Agricultural plastic products and their typical polymers (FAO, 2021).

The most important functional additives are light stabilizers, antacids, long-infrared radiation blockers (range 7 to 14 m), surface tension modifiers, short-infrared radiation blockers, and luminescence additives (Diaz Serrano, 2001). Another important additive is the blocker of the infrared fraction of solar radiation (known as NIR), near infrared, between 760 and 2500 nm. This additive when incorporated into a plastic sheet placed in a greenhouse, prevents the entry of heat radiation, limiting the heating of the greenhouse, which allows to reduce the greenhouse effect in hot climate zones (Verlodt, 2000). They are designated as PE-LD (long duration) or PE-UV (ultraviolet) (Castilla, 2004). Other used plastic materials are ethylene-vinyl acetate copolymer (EVA) and plasticized polyvinyl chloride (PVC). Polycarbonate (PC), polymethyl methacrylate (PMMA), rigid PVC and fiberglass-reinforced polyester, among others, are also used as rigid plates (Castilla, 2004).

EVA copolymer is a copolymer obtained by the same polymerization system as PEBD. Its optical properties are slightly different from those of polyethylene, present a higher PAR transmission and less turbidity and the thermal ones are better (figure). These thermal performances (long IR transmissivity) depend on the content of vinyl acetate, being 12-14% the most usual. Its main disadvantage lies on its tendency to creep when cold, which is unsuitable for windy areas (it stretches but does not recover well). As it gets dirty easily, it is usually used in multilayer films. EVA films can be very transparent to light ("glass" variant) or opal type (translucent), with great diffusing power (Castilla, 2004).

PVC film has optical properties similar to EVA, but better thermal properties (Table 1). It attracts dust, like EVA. Their widths are limited (6.5 meters with extrusion, 2 meters with calendering) and have little resistance to tearing, which is solved by incorporating a weft that prevents tearing and breaking. Its cost is higher than polyethylene and for this reason has a limited expansion in the Mediterranean area (Castilla, 2004).

Table 1. Greenhouse cover material characteristics (Castilla, 2004).

Characteristics	**PE**	**PE-LD**	**PE-IR**	**EVA**	**PVC**
Thickness (mm)	0,10	0,18	0,18	0,18	0,18
Weight (g/m2)	92,00	165	173	179	230
Transmission Photosynthetically active radiation (PAR) - Direct	91%	88-90%	85-86%	0,9	0,9
Transmission PAR - Diffuse	90%	86%	86%	0,76	0,89
Transmission Long Wave IR	68%	63-65%	<25%	18-27%	10-15%
Duration in mild weather (harvest periods)	1	3 or more	3	3	2

1.2 Plastic cover as a waste

Since their introduction in the early 1900s plastics have evolved and widespread across the globe in a variety of uses among all types of sectors including food packaging, agriculture, industry and construction sectors. This is a problem growing globally because plastic production trend is growing continuously (Nwafor & Walker, 2020; Geyer et al., 2017; Jansen & Henskens, 2019). In the agriculture sector farmers have made large use of it in their day-to-day basis for several uses improving the efficiency in their production (Jansen & Henskens, 2019). Though they have benefits due to its cost, durability and abundance, its appropriate management, disposal and/or reuse along their lifespan, however, has not reached the production chain with the same speed leaving a great amount of residues flowing into rivers which will transport them latter to the sea (Van Emmerik, et al., 2020). The Andalusian coast in Spain is a great example of the mismanagement among the agriculture sector which results in large macroplastics entangled on the vegetation that grows on riverbeds or deposited and accumulated on their way to the marine environment (Crumbie, 2021; Martin-Lara et al., 2021; Lobelle et al., 2022).

At the end of their useful life, APW is often abandoned in the fields or next to dry riverbeds and watercourses (Figure 4). Significant amounts are also disposed in landfills or buried into the soil (Briassoulis & Babou, 2013) (Figure 5). This is mostly composed by plastic cover sheets used on greenhouses, mainly that supposes the order of 2,000 to 2,260 kg.ha-1, every two or three years on the Andalusian coast. Other plastic materials, of minor importance are the sheets used in double layers, padding, as well as polypropylene raffia threads and discarded irrigation pipes.

Literature review usually addresses plastic pollution referenced to consumer objects and to agricultural residues flowing on rivers. There is a substantial gap to fill with respect to other seas and oceans since dry river beds do not behave as rivers continuously flowing towards the sea: either they are not active at all and act as waste reserves collecting all the plastics abandoned or dumped for long periods of time or they "overflow" (by this term they are known when they are flooded and the flow is rough). When this happens, water impulses and propel large amounts of waste towards the bottom of the sea with energy (Montero Montero, 2022).

Consequently, rainstorms mechanical processes sets residues into the ground, latter these plastics will be fragmented into smaller pieces that will end into the marine system. The negative impacts of plastic marine litter in the case of APW is not only the fragments that can be ingested by marine animals, but before they degrade and break into smaller particles due to physical fragmentation by mechanical forces like water flow and abrasion by sediments or chemical degradation by the action of the sun and other factors (van Emmerik, et al., 2022), they also present a peculiarity: since plastic sheets are large, when they are deposited on the seabed, they cover large extents of surface area blocking the carbon exchange between the column of water with the atmosphere and the sea bed, suffocating the organisms allocated in the bottom. This is accounted for by the rotten smell that the trawlers extract when fishing right after "overflows" in dry riverbeds.

Figure 4. Dumped plastics are scattered all over Castell de Ferro basin in the Granada coast.

Another important reason is that APW impacts directly on economic sectors linked to the typical life in coast such as fishing and tourism. Polluted ecosystems discourage tourism which leads to economy retraction and lack of job opportunities and in consequence, lack of incomes while increasing maintenance costs to the fishery sector and municipalities for cleaning campaigns.

To sum up, plastics are a growing problem that should be tackled on the source. For this reason, is important to highlight the need of validating a useful tool for authorities and researchers for assessing plastic macro-litter coming from agriculture for further study, prevention, reduction, management and removal strategies on the sector.

Figure 5. Agriculture plastics buried into the soil during field surveillance.

1.3 Environmental impact

The APW represent an environmental and economic problem an at the same time brings out a challenge to be exploited in order to recover energy and reduce the amount of agricultural plastics produced with fossil raw resources (Vox et al, 2016). Therefore, the correct evaluation of the environmental impact of greenhouse cultivation requires methods that integrate its various aspects from a global perspective. One of the most widespread methods for this purpose in various sectors of economic activity is the LCA (Life Cycle Assessment) life cycle analysis (Antón et al, 2007). Since it allows evaluating the environmental damage attributable to a product or an activity throughout its life cycle, that is, from its origins as raw material to its end as waste (Antón et al, 2007). The LCA method considers not only the environmental effects derived from the production process (for example, groundwater contamination) in the case of greenhouse cultivation, but also takes into account all other aspects (environmental impact of manufacturing the structure of the greenhouse or impact of the discarded greenhouse) capable of influencing the natural environment throughout its life cycle. The European Union published in the ISO-14040 standard the LCA methodology that, in addition to defining its objective and scope, includes the preparation of an inventory of inputs and outputs, the analysis of the impact associated with these inputs and outputs, and the interpretation of the results. The LCA is, in short, an eco-balance that quantifies the environmental impact, breaking it down into categories such as: energy demand, water use, land use, climate change, ozone layer depletion, (Schnitzler, 2003; Antón et al, 2007).

Methodologies such as LCA have made it possible to fine-tune "quality systems" that incorporate recommendations to producers on advisable agricultural practices to minimize environmental impact. The few existing studies on LCA in Mediterranean greenhouses highlight the interest of recirculating drainage water in soilless cultivation and underline the low impact of Mediterranean greenhouses, in terms of energy use, compared to greenhouses in northern Europe. The environmental aspects connected to agriculture must be assessed and taken into account in spatial planning including layouts with suitable locations for waste management. For this reason, Geographical Information Systems (GIS) constitute a necessary support tool which can provide very useful assistance for landscape planning and assessment because of their ability to capture, store, retrieve, model, manage and display, organizing large amounts of spatial data and therefore reducing collection, transport, transfer and disposal to final destination sites for recycling or elimination (Vox et al, 2016).

Discarded plastic pollutes water bodies posing negative impacts to the marine species such as blockage of the gills or the digestive tract, damage to the epithelia and internal injuries, pseudosaturation and reduced food intake, poisoning by contaminants and additives present in plastics, translocation to the vascular system and tissues, pathogen infections in the biofilm (Renaud et al, 2013; Sussarellu et al, 2016; Smith, et al., 2018). Subsequently, this problem impacts back human health through the food chain and causes significant risk with the possibility of microplastics serving as pathogen vectors (Bhuyan, 2022; Smith et al., 2018).

1.3.1 Types and amounts of plastics produced

In 2010 over 265 million tons of plastic were produced worldwide, 5.3 million tons were used in agriculture representing 2% of this volume. In Italy the average annual consumption of agricultural plastic materials accounts to more than 350,000 tons. (Picuno, 2014; Briassoulis & Babou, 2013). This number was estimated to grew to 7.4 million tons while representing the same two percent (2%) of the most recent estimation of the global plastic production of 359 million tons in 2018 and 368 million tons in 2019 (Sintim & Flury, 2017; PlasticsEurope, 2020) and Italy's average annual consumption grew to 372,000 tons. In 2018 the total film sales by country accounted to 533,310 tons from which Spain accounts sales for 93,000 Tons accounting for 17%. Furthermore, the agricultural plastic industry forecasts global demand for greenhouse, mulching and silage films to increase from 6.1 million to 9.5 million tons in 2030 (Figure 6) (FAO, 2021).

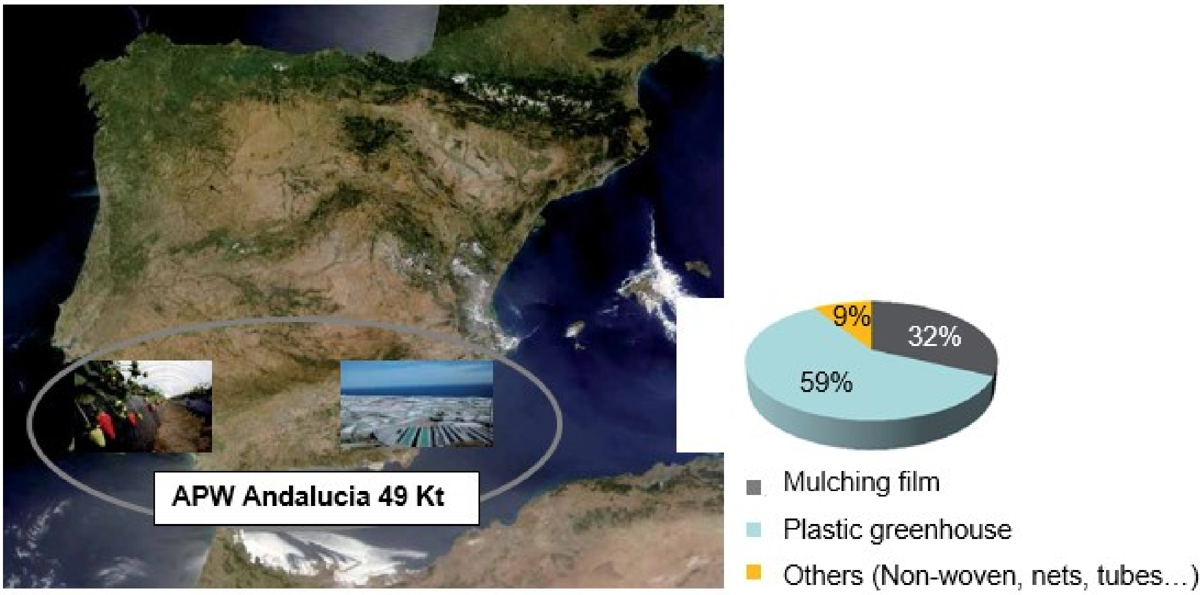


Figure 6. APW Generation in Andalucía 2016 (APE Europe, 2022).

In regards to the plastic types products used in agriculture, estimations raise to sixty-three percent (63%) used for silage for animal food and mulch, sixteen percent (16%) used for greenhouses, eleven percent (11%) used for twines, six percent (6%) for piping and accessories used for irrigation and one percent for nets (1%) (FAO, 2021). This numbers are similar in several sources as seen on figure 6, this can be confirmed to the estimations performed by the Agriculture Plastic & Environment (APE Europe).

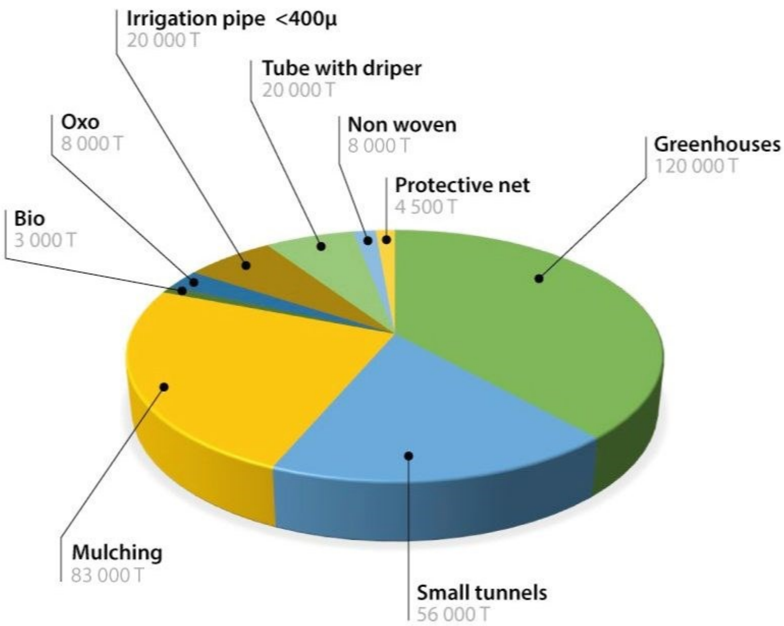


Figure 7. Plasticulture for Vegetable production, sales by products in Europe in 2019 (APE Europe, 2022).

1.3.2 Agriculture plastic waste management

Order MAM/304/2002, emitted on February 8, publishes waste recovery and disposal operations and the European List of Waste (LoW), establishes a taxonomy within which APW appears in chapter 02, code 02 01 04 (plastic waste except packaging). It should be noted that there may be some overlap, or possible double location or origin, of some LoW residues.

Most Autonomous Communities have poor control on management and generation of APW. Added to this is an insufficient level of reuse, recovery, recycling, use of this waste as second use material or as secondary raw material, a limited use of systems and technologies aimed at reducing the volume of waste generated, and a scant perception of the problem and its origin.

At the EU level, an ambitious multinational project began in 2006 in which 7 member countries participate (one of them Spain, through of three technical entities) with this same purpose; it is the initiative "Labelagriwaste"), whose development will last three years (Briassoulis, et al, 2010). Therefore, it should be noted that for some time now, in EU countries, efforts and investments in RDI programs have been intensifying to improve APW management. The Environmental Ministry in Spain has been granting aid to these projects over the last few years.

1.3.3 The management of plastics waste for agricultural use APW

In recent years, some Autonomous Communities in which there is a powerful horticultural sector using plastic, have perceived the importance of the problem of the management of APW due to the volume of waste that they can generate and their impact on the management systems of other waste fluxes (Barres Benlloch, 2007). For appropriate management, it is important to ensure that large generators of APW declare to the competent authorities what and how much they produce and manage.

Thus, there is an obvious need to improve and expand the adequate collection, treatment and transport of APW in some geographical areas of the Mediterranean coast, where the largest amount of this waste is concentrated due to the fact that current logistics systems are insufficient. This must be one of the priority objectives since the real possibilities of increasing recycling rates depend on the good organization of the collection and management circuits.

1.4 The principle of responsibility in the generation and management of APW

Extended producer responsibility (EPR) is a concept in which the holder or producer of the waste must assume the costs of its appropriate environmental management, internalizing them in the financing of the processes that generate them as a cost, exit case studies have been demonstrated in South Africa, UK, France and Chile. (Pazienza & De Lucia, 2020; Tudor & Dutra, 2021). It is also stated on title IV Law of waste 07/2022 (Law 7/2022, on residues and contaminated soils for a circular economy, 2022). This ensures no damage is caused to the environment through proper waste management, involving its externality (the cost affecting public management and environmental affection) which at the moment is mandatory for batteries, vehicles, mineral oils, containers and electronics among others.

Currently, the Law on Waste 07/2022 defines the obligations in the design, production and waste management required to the producers, either individually (through deposit, refund and return systems) or through collective systems (Aitex, 2021; Montero Montero, 2022). Since applicability of individual systems for the case of APW would not be efficient, this research will focus on collective systems.

1.5 Collective Systems of Extended Producer Responsibility (SCRAP)

The Collective Systems of Extended Producer Responsibility are organizations managed by non-profit entities which can take different legal forms (i.e. association, public limited company, foundation, etc.) that allow companies (producers) to fulfill their EPR obligations through them, collaborating financially with the operation of the system.

According to this model, every producer must pay a management fee intended for collection and treatment of the product (in this case APW) to the responsible entity. The management fee or rate has an impact on the price of the product and is usually transferred to the customer (Montero Montero, 2022).

To facilitate the collection of this waste, the entity arranges agreements with the regional authority so that the local governments for example, are the ones who carry out the collection, in exchange for a remuneration. According to the European Directive

((EU) 2018/851) Member States need to carry out a separate collection, before specific objectives for reuse and recycling are established. In application of the "polluter-pays" principle, producers have been involved in the prevention and organization of waste management, promoting management in accordance with the inspiring principles of legislation Law 22/2011, of July 28, on waste and contaminated soil since it addressed the "Extended responsibility of the product producer" (Aitex, 2021).

To this moment, specific regulations developed for each waste stream include the obligations to which product producers are subject in relation to the waste they generate (financing of its management and the fulfillment of objectives), as well as the modality of fulfillment of these obligations. Among these, the creation of integrated management systems (IMS) is contemplated, an option that has finally been the most common practice for some regulated waste flows in waste stream such as ECOEMBES for containers, SIGFITO for phytosanitary products and MAPLA (Environment, Agriculture and Plastics) which is a non-profit association created by producers of plastics for agricultural use to organize a management system for non-packaging plastic waste. Nevertheless, the study of the problem for the farmer is diverse since it lacks authorized managers or solutions that really adopt a sustainable model, meanwhile the alternatives within their reach barely reach management single part of the waste along with many others that greatly limit its use (Martinez, 2022).

France stands out as a reference model since it is the only country in Europe that has an Extended Producer Responsibility system for certain products like building construction products, motor oils, plastic tobacco products and fishing gear that contains plastics and commercial packaging among others. They have opted for a collective system in which an entity is accredited by the Government and the brands are required by law to pay a contribution with which the entity pays the plants based on the tons of products that classify. For this case, municipalities that communicate about the separation and collection of different waste streams are also rewarded. Since its implementation, France has improved the proportion of used products collected for reuse and recycling, which also means preventing them from reaching landfills. To sum up, the percentage of recycling is key; the basic rate paid by the brands is defined by the weight of the product, regardless of the materials or their quality. In this modulation system, since reward material reduction in manufacturing or the recyclability rate is accomplished, the more environmental criteria companies meet, the less they will pay (Aitex, 2021).

1.6 Systems and technologies for the prevention, monitoring and management of APW

To date, the available bibliography and comparative technical documents on the data regarding APW flows and ecological quality of existing technologies, including the most advanced countries, is still very limited. In the case of Autonomous Communities that include APW in Spain, the information is incomplete, this can be attributed to the lack of verified statistics and data, and to the fact that the plans and inventories have not been updated (Barres Benlloch, 2007). Recently efforts have been made to characterize plastic sources, accumulation and transport through the use of remote sensing. Satellites are being used widely to monitor plastic and litter patches at river and marine scale ecosystems (Tasseron, et al, 2021).

Thus, Unmanned Aerial Systems (UAS) used with the assistance of Geographic Information System (GIS) tools can be a solution at a local scale for addressing this gap in knowledge.

The implementation of Better Available Techniques in agricultural and livestock production is fundamental in Agriculture Plastics prevention as far as AP use is concerned, including those used to prevent chemical treatments with synthetic phytosanitary products.

The introduction of the waste prevention factor Art 1. 2) Law 07/2022 in general and specifically in the definition of these Better Available Techniques in Spain is considered a priority, in compliance with Art. 2. r) 07/2022, Law of Waste but again as stated previously on Law 10/1998 Art. 9.2 10/1998 and 22/2011 this not address APW as it specifically states that APW are not included (Pnasseau, Zerger, Roth, & Canova, 2018). APW production prevention implies RDI on APW and other longer-lasting substitute materials, as well as the performance of comparative studies and analyzes and life cycles to prevent such residues as much as possible (Law 7/2022, on residues and contaminated soils for a circular economy, 2022).

Secondly, reusing APW, when technically possible, constitutes the next best management option. It is stated on the preamble of Law 07/2022 which looks forward to prevent pollution and contribute to the ODS related to marine litter. Nevertheless, it seems contradictory that APW are not included on this section. Reuse is a valid element to reduce the generation of APW. Promoting reuse, to the extent permitted by best available techniques, should therefore be a priority (Parlato, et al, 2021; Nanna, et al, 2018; Law 7/2022).

The next priority, after prevention, is recycling. Among the many benefits obtained from these treatments such as raw materials savings, APW mass reduction destined for disposal, the Thematic Strategy on Waste Prevention and Recycling proposes, as one of its main objectives, to achieve what it calls a "recycling society" (Jørgensen, et al, 2006). Plastics can be categorized into thermoplastics and thermosets based on their behavior when heated. Among its principal characteristics is that the first one can be remelted into a liquid, while thermosets cannot. Promoting initiatives aimed at expanding the range of recyclable waste and increasing the recycling rate of recyclable waste has to be a must element of the waste policy in the coming years. Thermoplastics account for about 85% of all plastics production (ACC, 2019).

Another option to the above mentioned is the energy recovery of non-recyclable plastic waste or those subject to solar radiation and highly degraded, with significant technical difficulties for recycling (case of some plastics from solarization of soils, greenhouse covers, others). This alternative can allow the use of the important calorific value of plastics, which is slightly lower than that of natural gas, and higher than that of paper, wood and other urban waste.

In practice, the use of the energy contained in synthetic plastic waste can be done in existing industrial facilities, as fuel substitutes, provided that certain ecological and administrative conditions are met; This modality does not require specific facilities, although it is often necessary to adapt the technology of the industrial plant in order to achieve the required ecological quality standards. To this end, it is considered of interest to prepare, develop and propose a harmonized methodology for the risk assessment of facilities that value APW for energy, and that in the case of newly created infrastructures, regulated procedures are proposed to obtain the corresponding authorization.

Finally, elimination is the last option of the hierarchy scale, what must be done with an APW when nothing else can be done. This is how it is included in the current Waste Law, this is how it is reaffirmed in the principle of five-level hierarchy approved by the

Ministers and in the Thematic Strategy on Waste Prevention and Recycling and this is how it is reaffirmed in the proposal for revision of the Framework Directive, currently under negotiation (IEEP, et al, 2010).

1.7 Legal framework

Regarding the legal framework in Spain, agricultural waste needs to be addressed by a specific law. Decree 73/2012 for the Andalusian Community lacks enforcement and regulations established are not compulsory (Reglamento de Residuos de Andalucía, 2012). The lack or inefficiency of APW management schemes in most of the European countries, the complexity and continuous update of the Spanish legislation and the lack on input and output data for APW use turns APW management complex and expensive as visually seen on figure 8 (Vox, Viviana, Blanco, & Scarascia, 2016). At the present time in Spain, plastics used in the agriculture sector are not specifically regulated as they are included in the Waste Law. The problem begins with its management due to the fact that agricultural waste differs from household waste in that the responsibility for its management lies entirely with its owner, meaning that agricultural waste should not enter the circuit provided for domestic waste by the municipalities, neither the collection, nor clean points. Therefore, the farmer (holder) must pay entirely for its proper management, abandonment, dumping and uncontrolled disposal are prohibited. Farmers are obliged to deliver them to a waste manager, for recovery or disposal, or to participate in a voluntary agreement or collaboration agreement that includes these operations. Within the framework of the Waste Law –07/2022- Art. 20 it is essential for the holder, to receive a document that justifies waste correct management delivered to third parties (Law 7/2022). Even if APW where included on this law, a supporting document would imply responsibility transfer from the producer to the new owner, in this case, the waste manager. It is important to remember that farmers abide, as in any business for maximizing profitability as well. Therefore, it is not surprising the fact that, without specific guidelines regarding collection points location, transfer stations location, transport and specific procedures related to waste characteristics and specially lacking enforcement, these procedures are lacking effectiveness and efficiency. Therefore, this element is essential for successful management and must be taken into account when a future framework is established for this case.

Figure 8.Management lacks effectiveness and efficiency.

1.8 Coastal Cities and agriculture on Andalusia

Andalusia is the most important region of Spain for plastic use in the agriculture sector, since it concentrates 70% of the surface of greenhouses, 72% of the crop area with mulches and 62% of small tunnels (Bláquez, 2003). For instance, the agriculture sector in Almería, employs 50,000 people and registers export for USD 2,880 million/year (FAO, 2021). In comparison to other economic activities, one of the characteristics of the agricultural sector lies in the diversity of materials and substances that are transformed into waste: some are dangerous, such as containers used in phytosanitary products and others like cover plastics used in intensive farming are bulky. Secondly, there is a broad diversity of uses for plastic products like packaging, containers, piping among others. Another important characteristic of plastic waste generated by intensive farming its geographical dispersion. To have an idea of the dispersion in the territory, Spain had 989.796 spread farms in 2009 occupying 23,752,688 hectares according to National Statistics Institute (INE, 2022). Although this number is relative, since certain farms are large. It is necessary to take into account all the smaller farms, which in turn generate very few amounts each year. In the southern agricultural province of Almeria in Spain, intensive horticulture makes use of large amounts of plastic film for greenhouses and mulching covering 31,000 ha. In terms of volumes, the published official statistics do not allow approaching the totality of the remains and waste generated in the agricultural field, about 15 percent of the plastic films are not collected for proper recycling or disposal and are illegally dumped into the soil or burned (Sanchez, 2020).

Figure 9. Agriculture Waste Plastic is visible on intensive farming areas on the Andalusian coast.

Another reason that is important to highlight is that proper management, must be based on the separation in origin and storage in good conditions. As such, it requires space, something that not all farms have since it is not required by any norm or ordinance, especially in the regions with a predominance of smallholdings and/or greenhouses. Finally, waste is generated and dispersed in such diverse conditions and volumes depending on the area and type of activity, that the problems to be dealt with and their possible solutions vary as much as agrarian reality in Spain. All these factors establish an urgent need to monitor the state of art along the APW chain in order to identify and assess the main challenges before any solutions are proposed.

1.9 Remote sensing and its application on APW monitoring

Remote sensing is the technology of recording images or portions of the Earth's surface from spacecraft, aircraft or other platforms in order to understand the surface by analyzing and interpreting those images (Richards, 2022).

Remote sensing using satellites has been a successful tool broadly used in recent times for monitoring plastic debris and floating litter on oceans from space (Biermann & Clewley, 2020). Nevertheless, there are fewer success stories using remote sensing for monitoring plastics on dry riverbeds where anthropogenic waste sets not far from its source and accumulates on its way towards the ocean (Geraeds, et al., 2019; Van Emmerik, et al., 2020). While performing plastic detection studies on a large scale over the oceans may be important in determining direction flows and big plastic accumulations, prevention approaches such as tackling its detection before they reach their destination should be the priority (Cózar, et al., 2021; Walther, Yen, & Hu, 2021; Mendenhall, 2018). Another reason is that plastic removal from oceans is a more difficult task with no less costs (Burt, 2020).

Sampling and monitoring methods and algorithms have been developed to measure the amounts of plastic floating on water. Furthermore, it is on land where the detection of litter plays a more imperative role, and it is here where actions can be taken to prevent plastics and litter from entering the ocean (Morales-Caselles C. &.-R.-G.-S., 2021). In contrast to satellites and manned aerial remote sensing platforms, Unmanned Aerial Vehicles (UAVs) are cheaper and have a more flexible use (Dukowitz, 2020). Massive image data can be obtained in short periods of time with UAVs saving lots of resources and improving efficiency in data collection. Another reason to highlight its use is that plastic detection on land is a task where fewer studies are being developed and drones play a far more practical role at river segment scales due to their ease of use, easy approach on difficult access areas, resolution adjusted to the needs of the case and reliability of the data delivered (Van Emmerik & Schwarz, 2019).

Monitoring source allocation of plastics before they enter the sea is relevant for improving waste management systems and taking actions for its correct disposal (Morales-Caselles C. V., 2021; Chen, 2021). In addition, drones play a more practical role than the use of satellites because of their easy handing and better-quality resolution over smaller and difficult access areas, thus they provide reliability in recognizing macrolitter and with the assistance of GIS they can be used as a useful tool for municipalities, academic researchers and decision makers for identifying plastic macro-litter coming from agriculture for further prevention, reduction, management and removal strategies on the sector (Martin, et al., 2018). Finally, technical requirements and a validated methodology for developing cost-effective, efficient and reliable monitoring tools is needed for using UAV and GIS for plastic litter detection and assessment.

1.9.1 Sensors

A sensor can detect energy coming from the Earth's surface, followed by some form of instrumentation, which can convert that measured energy into an electrical signal, and a means for sending that signal to the Earth's surface. On the ground, the signal is composed into the form of images of the landscape over which the platform has flown. In the case of UAS, the images are formed in recorded on the platform itself and then downloaded when the platform returns to the earth's surface. For this case, the energy that the sensor detects is the sunlight reflected from the surface.

According to (Richards, 2022) remote sensing is divided into four blocks. The first block is the energy that is detected by the scattered sunlight radiation from incident radio waves on the platform. Alternatively, the energy can be radiated by artificial sources such as radars or laser.

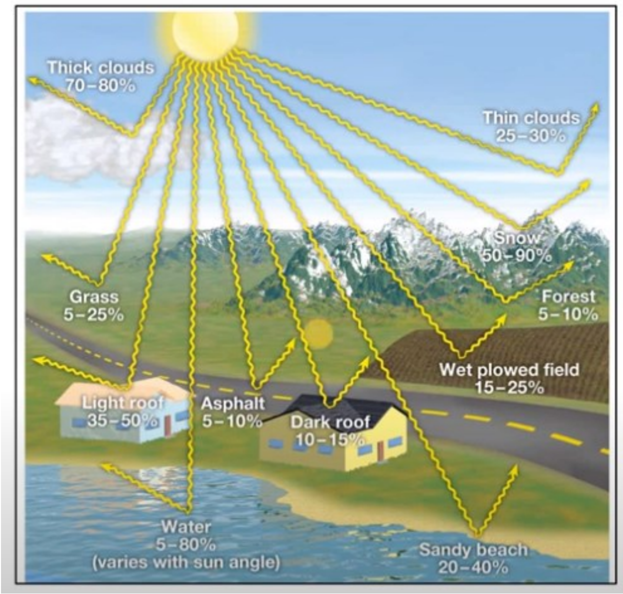


Figure 10. Absorption and reflection of EMR (Amidon, 2020).

The second block is the downlinking of the signal which carries the information recorded by the detector followed by the subsequent translation of that electrical signal into digital imagery spatially composed of discrete picture elements called pixels. This normally occurs in a suitable facility on the ground. Following, the image data recorded by the platform will have embedded errors due to brightness and contrast relative to the actual brightness and contrast of the scene being imaged. But there can also be errors in the geometry of the image compared with the spatial arrangement of features on the Earth's surface. Subsequently once those errors have been corrected, the images are ready to be interpreted through applications by an analyst with the assistance of computer algorithms. To sum up, the first three blocks get the data ready, and the last block consists in the interpretation and application.

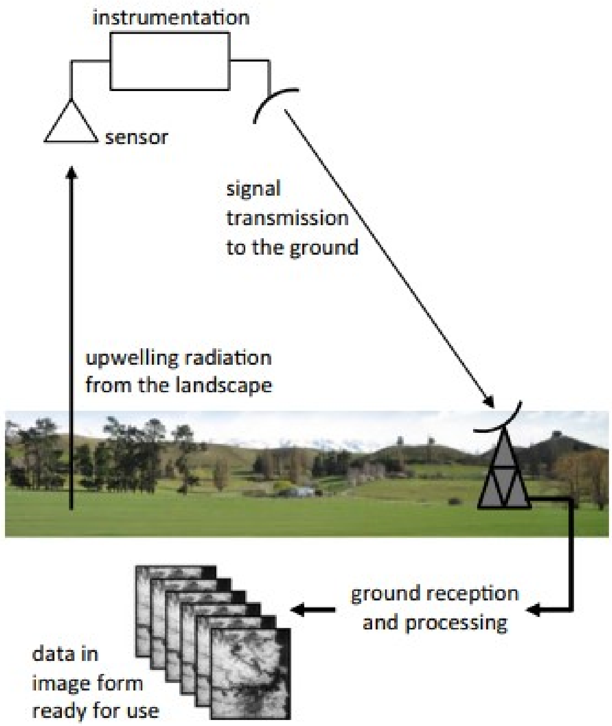


Figure 11. Signal flow in a remote sensing system (Richards, 2022).

The most substantial characteristic of the image data provided by a remote sensing system is the broad range of wavelengths for analysis. At the top, it shows the electromagnetic spectrum from ultraviolet through to long radio waves. In the infrared range, it is separated into reflective and thermal infrared.

Among the different platforms that are routinely used for gathering remote sensing imagery, the most common platform has been the earth orbiting satellite and more recently, imaging from drones has become popular due to their practical use and low relative cost. Nevertheless, there are several differences among spacecraft, aircraft, and drones for imaging. Among the principal characteristics is that satellites can cover greater areas whereas drones can record images with higher spatial resolution because of their proximity to the surface. Since earth surface materials selectively absorb sunlight at different wavelengths giving the appearance of color in the visible range, optical remote sensing systems acquire in the ultraviolet, visible and near to middle infrared ranges of wavelengths covers approximately 0.4–2.5 μm (Richards, 2022).

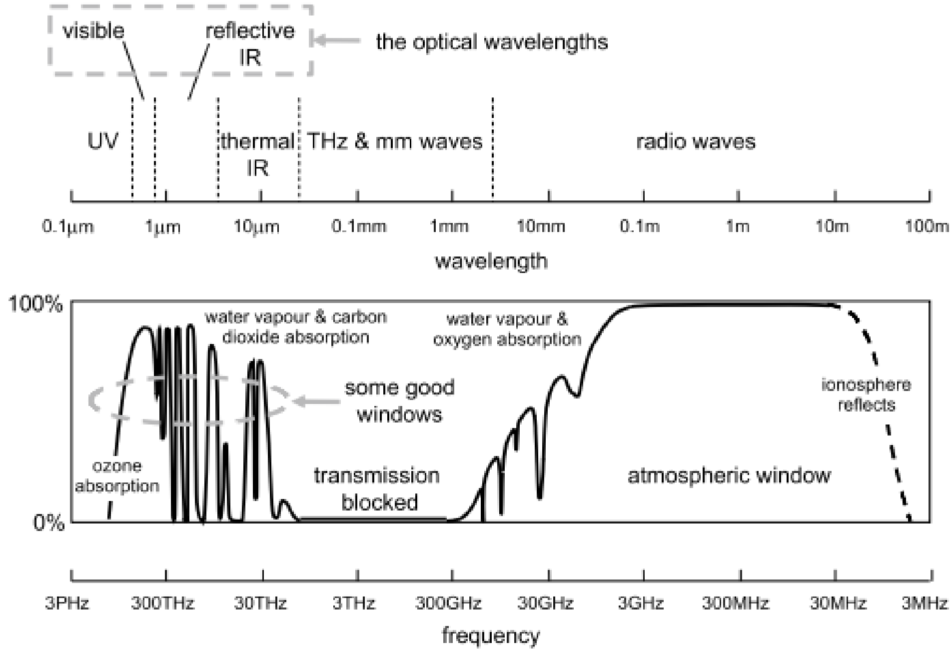


Figure 12. Electromagnetic spectrum and transmittance showing atmospheric windows used in remote sensing (Richards, 2022).

Optical remote sensing instrumentation operates mostly between the range of 0.4–2.5 µm. Figure 13 shows how the different types of surface cover (vegetation, soil and water) reflect sunlight over the wavelength range. Consequently, particular selection absorption characteristics is showed and this is directly linked to the cover material unique biochemical and biophysical composition i.e. water reflects about 10% or less in the blue-green range whereas soils have a low reflectance (dark color) with dips centered at about 1.4, 1.9 and 2.7 µm due to moisture content. (Richards, 2022).

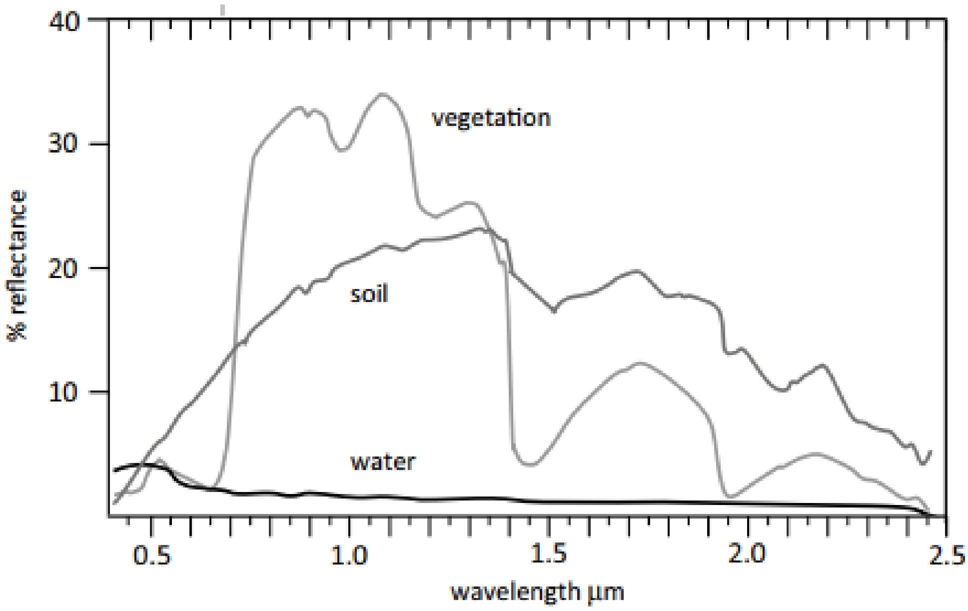


Figure 13. Spectral reflectance characteristics in the visible and reflective infrared range for three common cover types (Richards, 2022).

1.9.2 Classification (Image analysis)

Classification is a mapping technique performed from the spectral measurements acquired by a sensor to a identify for each pixel what is on the ground (Richards, 2022).

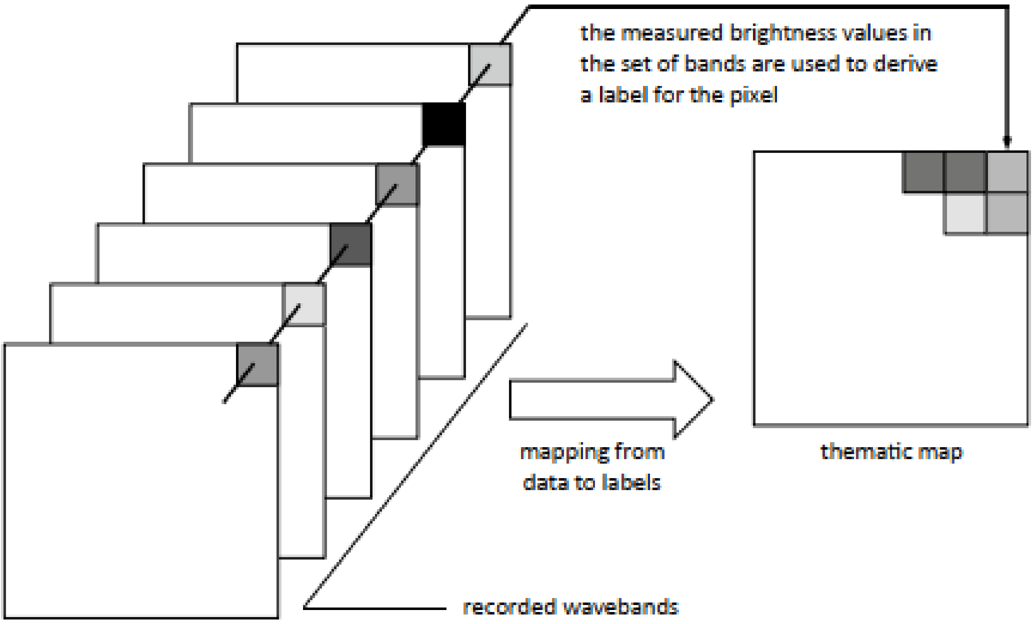


Figure 14. Classification as a mapping from measurement or spectral space to a set of labels (Richards, 2022).

Humans and computers have different capabilities (Table 2). Human beings are easily able to discern crop fields, roadways, lakes, and other shapes and forms like agroplastics with their locations, whereas quite complex software algorithms are required for shape and spatial analysis performed by machines. From this we can conclude that successful image interpretation exercises in remote sensing derives from creating a synergy from both worlds: the skills of the analysts with the powerful properties of computer algorithms.

Table 2. Human vs computer capabilities comparison (Richards, 2022).

Photointerpretation (human analyst)	Quantitative analyisis (computer)
On a scale large compared with pixel size	Can work at the individual pixel level
Less accurate area estimates	Accurate area estimates are possible
Limited ability to handle many bands	Full multi-band analysis is possible
Can use only a limited number of brightness values in each band (about 16)	Can use the full radiometric resolution available (256, 1024, 4096, etc)
Shape determination is easy	Shape determination is complex
Spatial information is easy to use in general	Spatial decision making in general is challenging

Many different algorithms are available for supervised classification. Irrespective of the one chosen, the essential practical steps in applying a classifier usually include:

1. Deciding on the set of ground cover type classes into which to segment the image.
2. Choosing representative pixels for each of the classes, for which the class labels are known. Those pixels are said to form training data. Training data sets for each class can be established using field visits, photo images or assessment of image products gathered from drone data. The result obtained is called a training set.
3. Using the training data to estimate the parameters of the particular classifier algorithm to be employed; the set of parameters is sometimes called the signature of that class.
4. Using the trained classifier to label every pixel in the image as belonging to one of the classes specified in step 1. Here the whole image is classified. Whereas in step 2 the user may need to know the labels for about 1% or so of the pixels, the reminder is now labelled by the classifier. This step is called classification, labelling or allocation. In the terminology of machine learning it is called generalization. It is in this step that we see the major benefit of supervised classification in remote sensing. Gathering labelled training data for each class can be expensive and time-consuming. However, that investment is rewarded significantly by being able to label all the other pixels in the image, with just the cost of running the classifier algorithm.
5. In connection with step 4, producing thematic (class) maps and tables which summarize class memberships of all pixels in the image, from which the areas of the classes can be measured.
6. Assessing the accuracy of the final product using a labelled testing data set. This is a crucial step if the results of classification are to be relied upon in practice.

The idea is to use human and machine-based resources in an efficient way in order to get the best results out of classification algorithms in such a way that applying human knowledge on a small part of the data produce an understanding of the whole image data set. Hence, the synergy between both must be optimal for proper image analysis.

2 Scope of the research

Because of relationship between land and sea and the pressure that intensive agriculture exerts on both ecosystems, it is essential to manage the plastics used for agriculture in order to prevent pollution in coastal areas. Therefore, waste management first steps are to detect, monitor, assess and propose actions aimed to reduce or eliminate the plastic waste, transforming the agriculture by focusing on reuse and recycling of plastic materials from a technical and biological circle economy perspective as this will lead to produce more with less, keeping on improving efficiency in production.

The **main objective of this study** is assessing the socioeconomical role plastics play in agriculture, detect, monitor and assess agriculture plastic waste in a study area and propose solutions to prevent, account quantities, flows and recovery.

To evaluate the role plastic plays on the agriculture sector and subsequently establish mitigating proposals to prevent, reduce and manage plastic use on coastal zones it is necessary to address the above mentioned facts. For this purpose, this research recommends the following systemic actions for the specific objectives:

Objective 1: Address the APW gaps in policy by assessing the current state of art for managing plastics on intensive agriculture zones in the study area

Objective 2: Address the gaps in knowledge by assessing agriculture plastic waste source, transport and distribution from a holistic approach.

Objective 3: Conduct a reconnaissance on the research area and delimit a study zone to perform the field activities for unmanned aerial vehicle plastic detection.

Objective 4: Establish a set of responses for surveillance and control of agriculture plastic waste to reduce or eliminate the issue and therefore improve the agricultural waste management to preserve the marine ecosystem from a circular and sustainable approach.

3 Research materials and methods

The methodology was developed under an integral approach for addressing plastic waste along its value chain on intensive agriculture to prevent plastic litter dumping along Mediterranean coastal cities. The scope was to establish the current management for the agricultural plastic waste flows (APW) and propose actions to tackle the main challenges. It corresponds to a combination of the following actions:

- Current state of art (legal framework and socioeconomical factors) assessment of plastics used on intensive agriculture
- Agriculture Plastic Waste identification and assessment on hot spots along the study area using remote sensing and geographical information system tools to create a database and understand the sources, fluxes and main hotspots for actions.
- Solution proposals for monitoring hot spots and APW recovery flows.

3.1 Establishing the current state of art (legal framework and socioeconomical factors) along the plastic value chain in agriculture

Data gathered was based on documentary review of publicly available primary data sources identified from published official reports and study research documents related to Agriculture Plastics and Waste in the intensive horticultural value chain, the current European legal framework for the management of plastic waste, the productive structure in farms and management practices, institutional statistics on the agriculture sector, economic data related to the value chain, and information regarding APW generation in the production process. In addition, field work was performed in the study area using informal interviews performed in 2021 covering different subjects regarding agriculture technology as well as waste management and recycling processes. Based on this knowledge and documentary review, flow diagrams and solutions to tackle key challenges were proposed.

3.2 Study area

The province of Granada is located in the south of Spain, at the Mediterranean Sea. It is part of the Andalusian region, and it is composed of 174 municipalities in 6 different counties. Its capital is the city of Granada. For this research, the study area will focus on Castell de Ferro located within the Gualchos municipal boundaries. This was chosen following the criteria listed below:

- Castell de Ferro is located in the coastal zone, specifically the shoreline of the tropical coast in the Mediterranean Sea.
- Because of its topography it has dry riverbeds with characteristics considered practical and adequate for conducting research in terms of accessibility and delimited areas.
- Castell de Ferro has a significant intensive farming with a noticeable lack of management among the county.

3.2.1 Castell de Ferro

Castell de Ferro, located in the province of Granada, is known principally for its tourism, its agriculture and its conservation of traditional constructions. However, the beachfront is full of modern apartments. Castell de Ferro is situated in the central part of Granada's coast. Near this location we can find El Romeral, Calahonda y La Mamola. The coast in Castell de Ferro is well known for its numerous caves and its beaches.

3.2.2 Demography

According to the National Statistical Institute of Spain, in 2014 Gualchos - Castell de Ferro had 2964 registered inhabitants, representing 59.58% of the total population of the municipality.

3.2.3 Coast

This part of the Costa Tropical is the least known by foreign tourists. Castell de Ferro, known for its clear waters, has some of the most beautiful beaches among the mediterranean coast. With its lack of infrastructure, this beach is still relatively untouched. It is an area of crops and intensive farming such as cucumbers, zucchini, peppers and avocados, most of which are for export to Northern Europe and other areas of Spain (Gualchos Municipality, 2022).

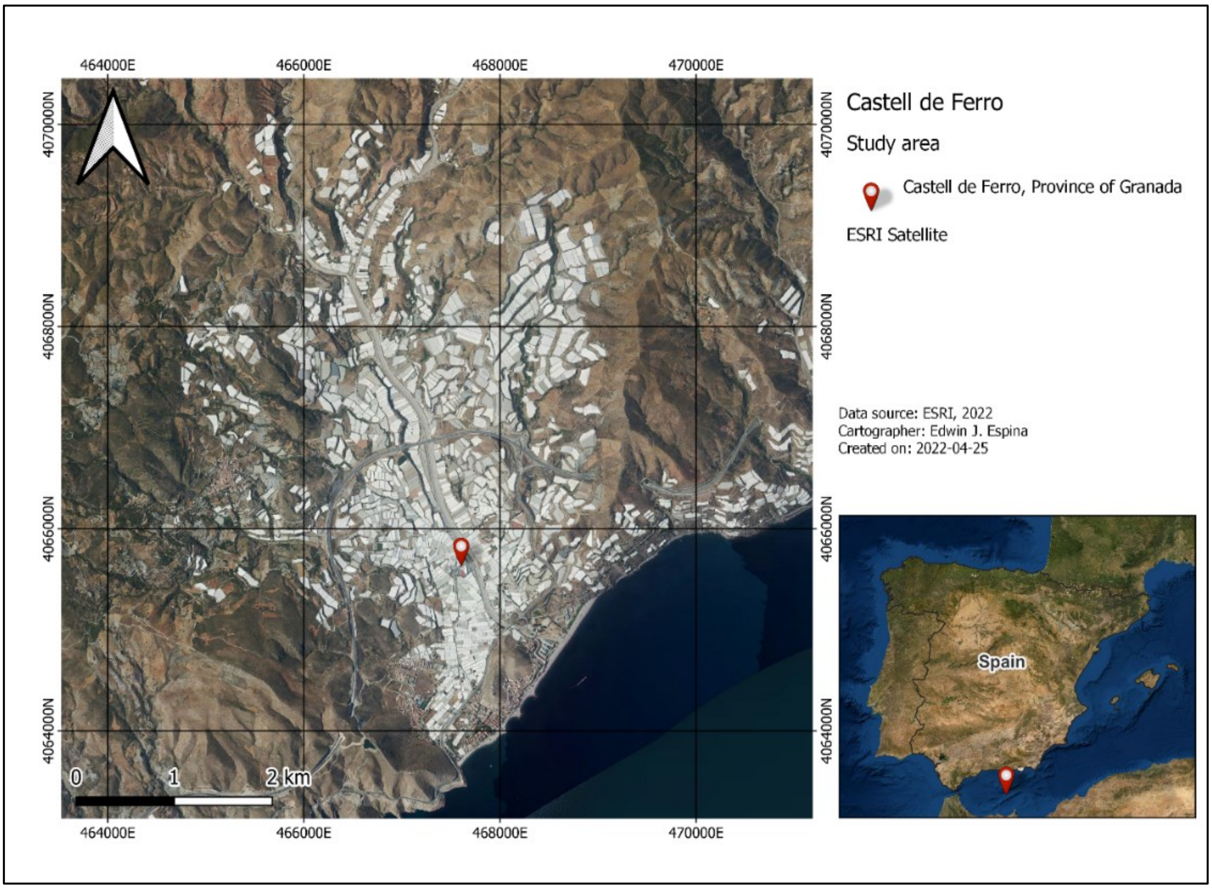


Figure 15. Study area: Castell de Ferro, Province of Granada.

Figure 16. Castell de Ferro is a coast town famous for its beautiful beaches and on risk of Plastic Litter contamination.

3.3 Agriculture Plastic Waste identification and assessment

3.3.1 Image collection on field study

The methodology was developed as an approach for detecting, monitoring and assessing plastic residues dumped illegally into the dry river bed within a delimited boundary in Castell de Ferro, on the Granada coast in Spain. Land use/cover, topography and socio-economic data and GIS analysis. Latitude and longitude were measured using a hand-held GPS. The catchment boundaries were delineated on a 30-m spatial resolution digital elevation model (DEM).

The aerial images were obtained from a UAV DJU Matrice 210 V2 equiped with a Zenmuse H20T sensor employed for the RGB image acquisition, and for the multispectral image a Micasense Rededge MX Red and Blue camera (Micasense, 2022) was used with the capability to detect 10 multispectral bands between the blue and NIR bandwidths: blue 444 nm (28), blue 475 nm (32), green 531 nm (14), green 560 nm (27), red 650 nm (16), red 668 nm (14), red edge 705 nm (10), red edge 717 nm (12), red edge 740 nm (18), and NIR 842 nm (57) (Figure 17).

Figure 17. Micasense dual camera system used for data collection. Left: DJI Matrice 210 V2 equipped with Micasense dual sensor. Right: Micasense reflecting panel (Micasense, 2022)

Before recommendations and actions are made by academic researchers and policy makers to prevent, tackle and manage plastic pollution from agriculture, it is necessary to identify where the macroplastics originate (source) and accumulate (location). The survey area involved a dry riverbed located in the city of Castell de Ferro on the coast of Granada in the Andalusian coast. To perform the survey, first it was necessary to conduct a field visit on land and perform a survey of the plastic pollution. Afterwards a study area was established and delimited. Once the area was delimited the data was collected, objects were counted and identified, pictures were taken on the objects to enable its identification.

3.3.1.1 Image acquisition

The UAV vehicle captured imagery along the dry riverbed which is the area where the survey is being conducted as shown in figure 18. With the RGB image, an image with a Ground Sampling Distance (GSD) of 1,30 cm was obtained. With this image, the maximum range allows to visually identify objects with dimensions from 20 cm and above, such as the cones used to separate the red, blue and green lanes. The detail flight of both the RGB sensor and the multispectral sensor were made in the same flight at a constant altitude of 40 meters. The GSD (Ground Sampling Distance) of the multispectral mosaic was 3.40 centimeters, while that of the RGB sensor was 0.56 cm. With this image resolution it was possible to differentiate objects from 30 cm and above using the help of the RGB image.

Figure 18. UAV performing flight for imagery data collection.

These images were then downloaded and processed using Pix4D mapper (Pix4D, 2021), a software that process the multispectral images and generates an (RGB) orthophoto in which two individual mosaics were created; one with the RGB and one with the multispectral image taken. The software performs the radiometric processing and calibration to calculate the irradiance and data from the downwelling light sensor (DLS) for normalizing each image for changes in the incoming radiation and sun orientation during each flight. As a result, ten single reflectance calibrated GEOTIFFs were obtained for the multispectral images and three for the RGB images. The high resolution RGB composite shown on the following figure was very useful for object comparison when creating Regions of Interest (Figure 19). The multispectral maps contained reflectance values ranging between 0.0 and 1.0 for each pixel. The GEOTIFFS were then processed with a QGIS 3.22.5 Białowieża (QGIS, 2021), a free license software with the assistance of the plugin tool for Supervised Classification called SCP (Congedo, 2021).

Figure 19. Orthomosaic output ready for analysis.

3.3.2 Litter surveying with mobile application

Several steps were performed to create the litter layers on QGIS. The first method was to identify and register each litter object on the study area through a mobile phone application. The procedure is the following: the points are saved on the mobile application and a picture of each litter item can be linked and saved with the characteristics that identify each object on Wikiloc application.

The method described provide interesting findings in key aspects of plastic identification in dry riverbeds: The first was that it was demonstrated to be a simple method for identifying macroplastic locations within the study area. The benefits of this action can be shared or handled as a tool with the help of other methods proposed for identifying, sampling and monitoring hot spot locations. The routes are saved by the Wikiloc application and the files can be later downloaded as kml or gpx files for uploading on QGIS or Google Earth (Figure 20).

Another important fact is that this allows to upload each item registered as a point vector in a point layer and saved as a layer file on QGIS as well. However, since the picture is saved into the app, when downloaded it does not retain its metadata attributes. For this reason, once the photo file is downloaded, each picture must be geotagged, this means to link each picture to its corresponding point. This was done by creating column datasets on the points layer attribute table for the description and one column for saving the picture file location, then each picture is attached to the points database in the attribute table by inserting its URL location and can be accessed as a hyperlink by mouse clicking on each point.

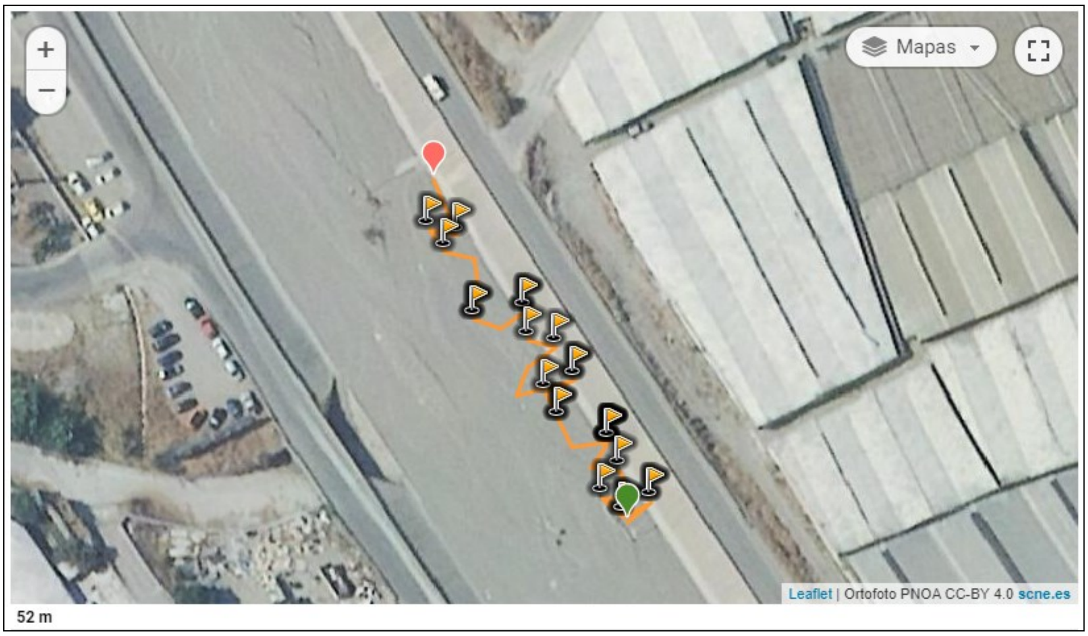


Figure 20.Wikiloc waste register over study area.

Since the points are linked to each picture and description on the application, this step can be done working either side to phone or side to the website for reference. The points are uploaded to QGIS and can be styled according to each sector color for ease of identification as shown in figure 21.

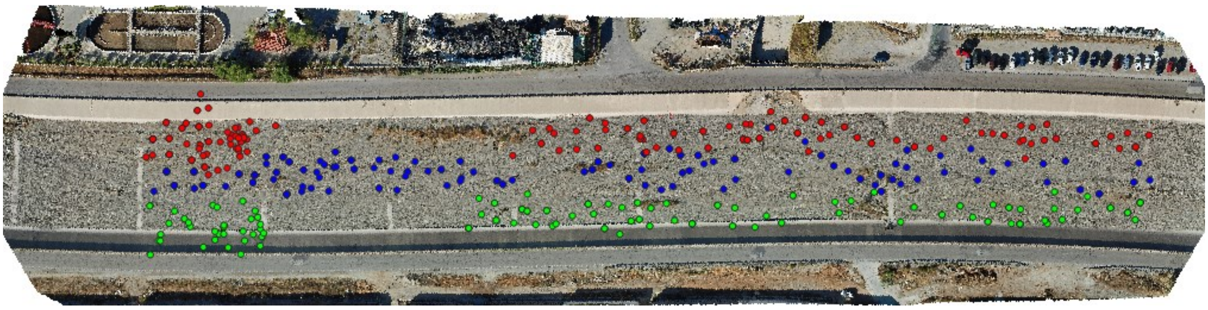


Figure 21.Points uploaded over map database.

During this phase, the dynamics changed from saving each object as a single item to saving groups of litter on picture. The reason behind this was to save time and resources. This was not the case on the green sector since it had less litter and there was not much vegetation nor plastic litter entangled between the vegetation, nevertheless, as the activities advanced to other sectors and litter accumulations were denser the registering was time and resources consuming and since the principal objective of this activity to collect agriculture plastic litter this decision was taken without affecting the main aim. However, it is important to recall that while this decision saved resources and time on field orthogonal pictures of plastic items are more precise and descriptive when comparing results with drone pictures. Finally, data interpretation is more clear and feasible (Figure 22).

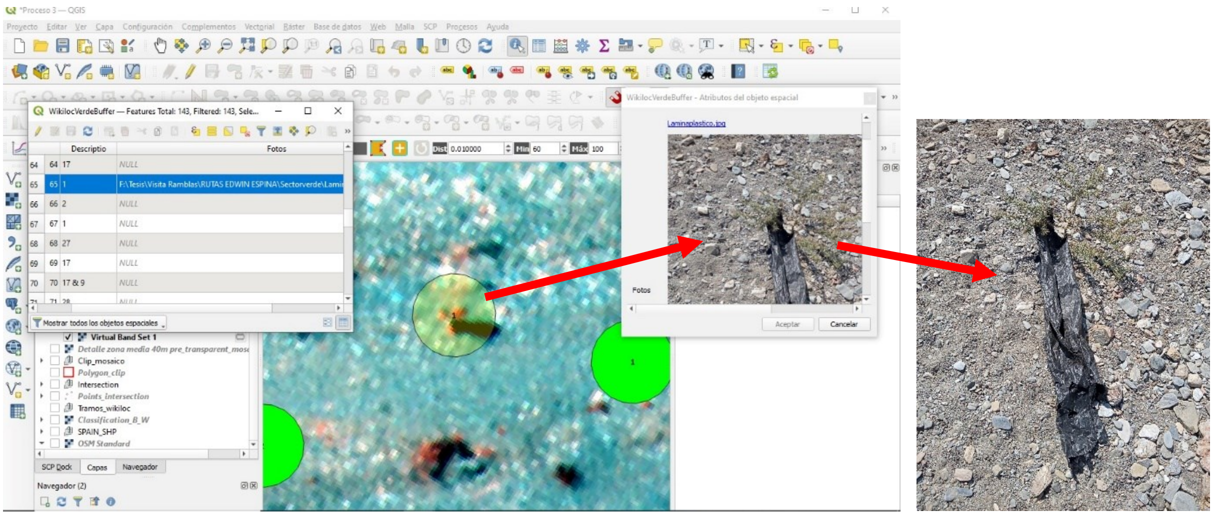


Figure 22. Picture attached to point attribute table.

To establish the study research area and delimit a boundary area to carry out the field activity, the actions were based on the main goals established and are described as follows:

1. Litter register: Due to the dynamic complexity of plastic source, transport and allocation, the first step of data collection was to identify a study area. A study area was delimited with cones and then divided into three rows and eight sectors for a total of twenty-four squares. Each row was classified with a color (e.g., red, blue and green) and each sector has the following measures: a length of 40 meters and a width of 11 meters (Figures 23 & 24).

Figure 23. Study area delimitation.

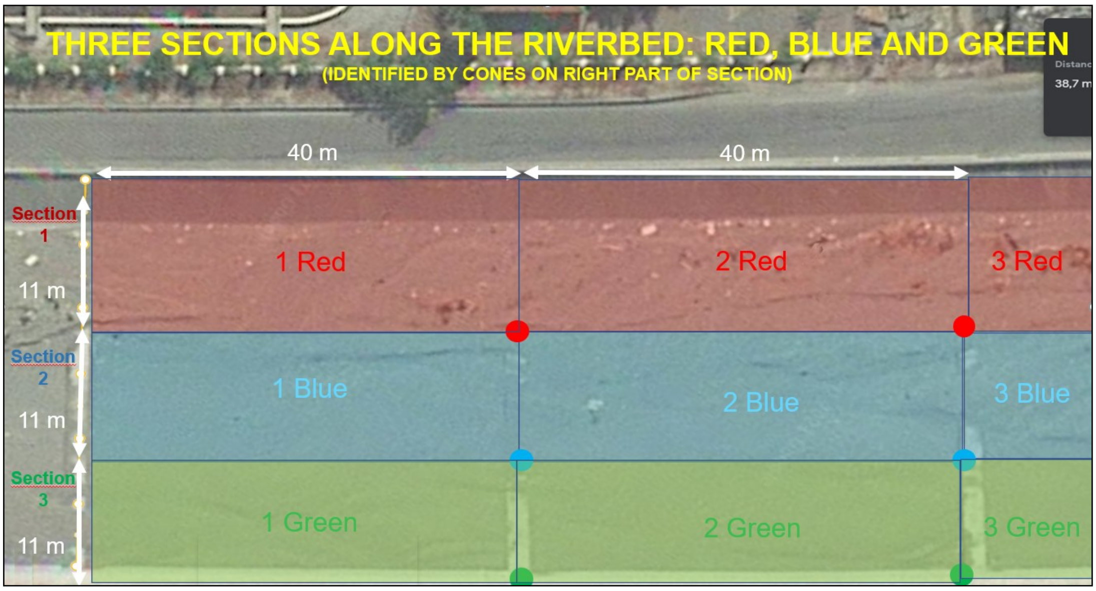


Figure 24. Sectors numbered from left to right and rows classified with colors.

2. Perform site visit on study area and elaborate litter register surveying over the boundary control area with the assistance of camera and GPS mobile application. This step was developed to ease data location with Wikiloc mobile application (Wikiloc, 2022). This application can be used for registering litter location with picture on outside areas allowing for creating or adding data to litter datasets at a particular location. In this way, each point can be saved with geographic coordinates, date, time and type of litter providing useful data for creating litter maps. Subsequently, on the field each volunteer accounted and identified each type of litter present. The litter was then categorized into categories for labelling respectively: agriculture origin plastics (LDPE, HDPE, PD, PP, PVC, PET), consumer products litter, metal residues, construction residues. This step is important to be acquainted with the impacts and outcomes of each source. This content was useful in further analysis to support and validate the representative pixels for each of the classes where classification was performed (Figure 25).

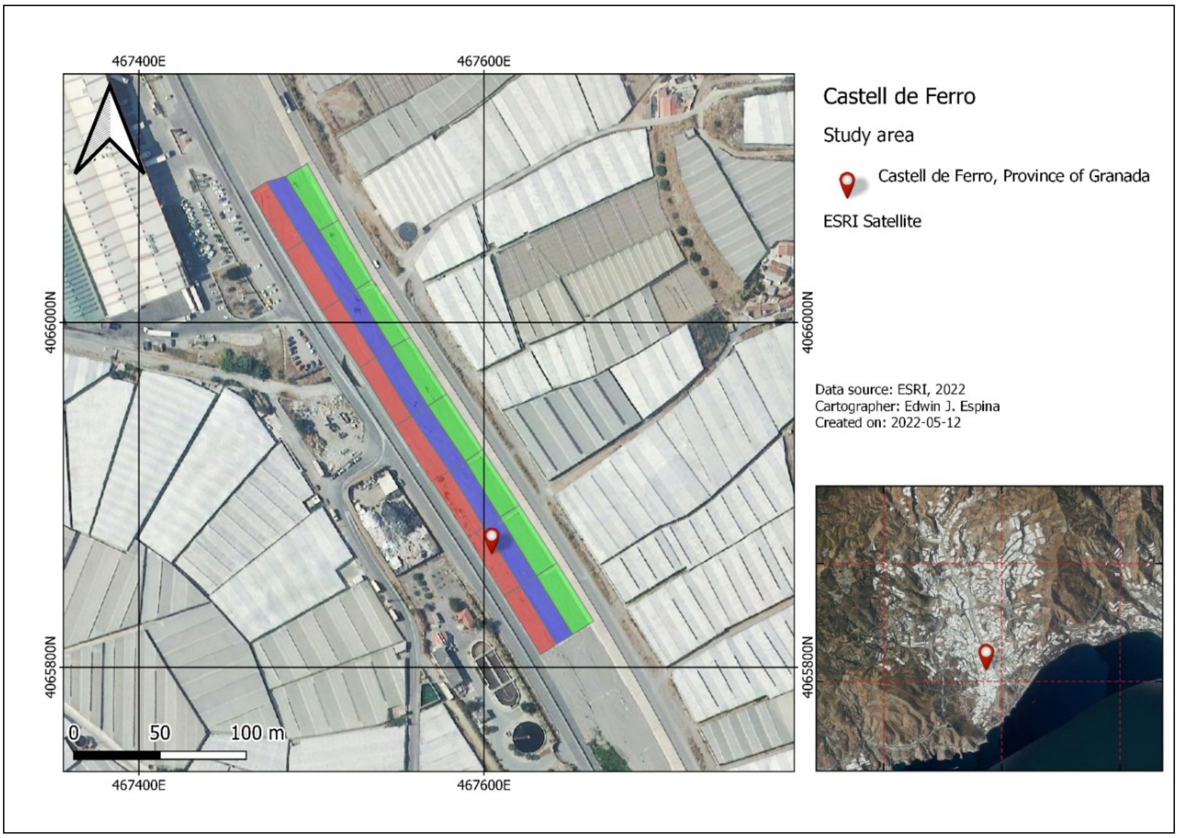


Figure 25. Study area location with sectors identified.

3. Verification on ground: The purpose was to obtain the coordinates of each litter object verifying if each object was detected by the drone sensor. As shown on figure 26, the routes were georeferenced using Wikiloc and the location of each object was saved as a waypoint with its respective picture.

Figure 26. On site litter register with assistance of GPS mobile application.

4. Litter withdrawal: Once the survey was performed, a cleanup campaign removed all the plastic and litter from the study area (Figure 27).

Figure 27. Litter pickup and withdrawal.

5. Execute the UAV flights and subsequently, collect, process and transform image data into products ready for application by the user. On this phase it is important to plan the mission and this implies establishing the flight altitude, the overlap, how many Ground Control Points (GCPs), where to set the GCPs, how to arrange the flight pattern. This steps are very important in regards to time efficiency on field and in office while retrieving the kind of data that needs to be surveyed for on this step the drone will collect multispectral and RGB images. The aim of this activity was to develop litter distribution models. The UAV vehicles flights were performed along the study area, the georeferenced images taken were later processed to identify plastic pollution objects (Figure 28). Plots were elaborated with the visits performed on July and September 2021.

Figure 28. Data collection imagery data over the study area with UAVs.

6. Process the acquired data imagery with PIX4D to obtain reflectance values, this step implies computation of Ground Sampling Distance (GSD) to derive metrics on items size and area, troubleshooting photogrammetry issues, selection of images, to get more accurate data until the data imagery is ready to be processed by the GIS software for image classification (Figure 29).

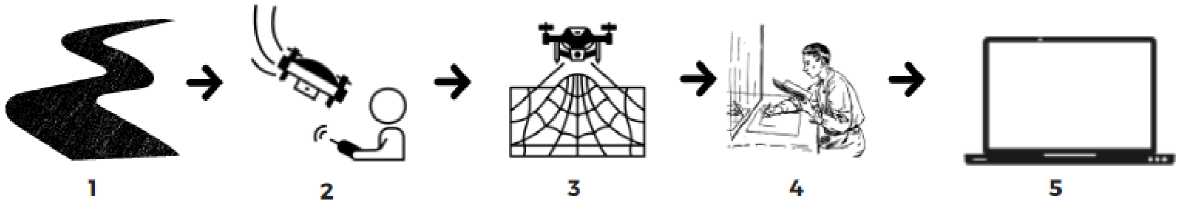


Figure 29. Imagery data processing workflow.

7. Once the data imagery is processed**,** image data analysis is ready to be assessed; assessing included labelling, performing litter vectorial shapefiles and generating classification which includes: training area selection, signature file generation and final classification. Then a set of steps to develop a validated process diagram for agricultural waste detection and monitoring must be established defining it as a tool procedure (Figure 30).

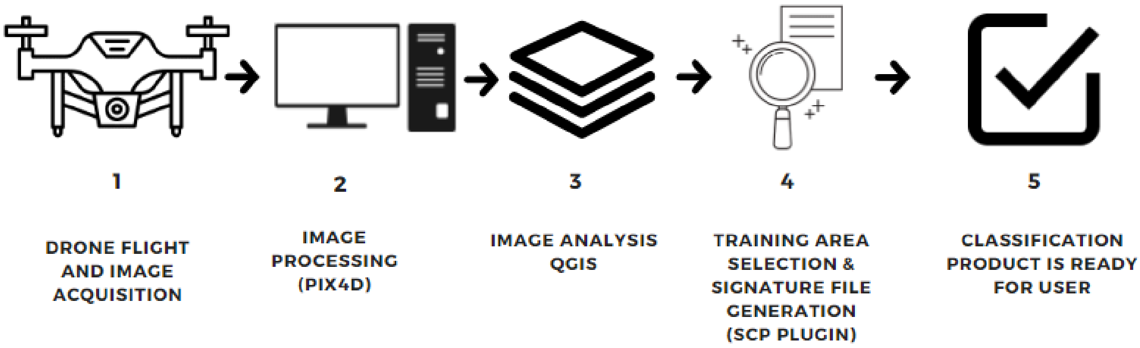


Figure 30. SCP Workflow for APW detection.

8. Establish a set of responses for surveillance and control to reduce or eliminate the issue and therefore improve the agricultural waste management to preserve the marine ecosystem from a circular and sustainable approach.

4 Results

The following section summarizes the results of the literature review which highlighted important existing research on market and policy instruments and drivers that encourage behaviour change for recycling in terms of source segregation of recyclable plastics. In order to better identify the costs and benefits associated with the different possibilities for managing APW, first it is necessary to identify the different types of costs among the different stages of plastic along the value chain; from production to the end of life and then through the waste management process: collection, transport, processing of waste and its final disposal (Figure 31). It is important to recall that the way in which collection and transport of APW is performed, impacts directly the success or failure of the alternative selected on its further recovery or treatment.

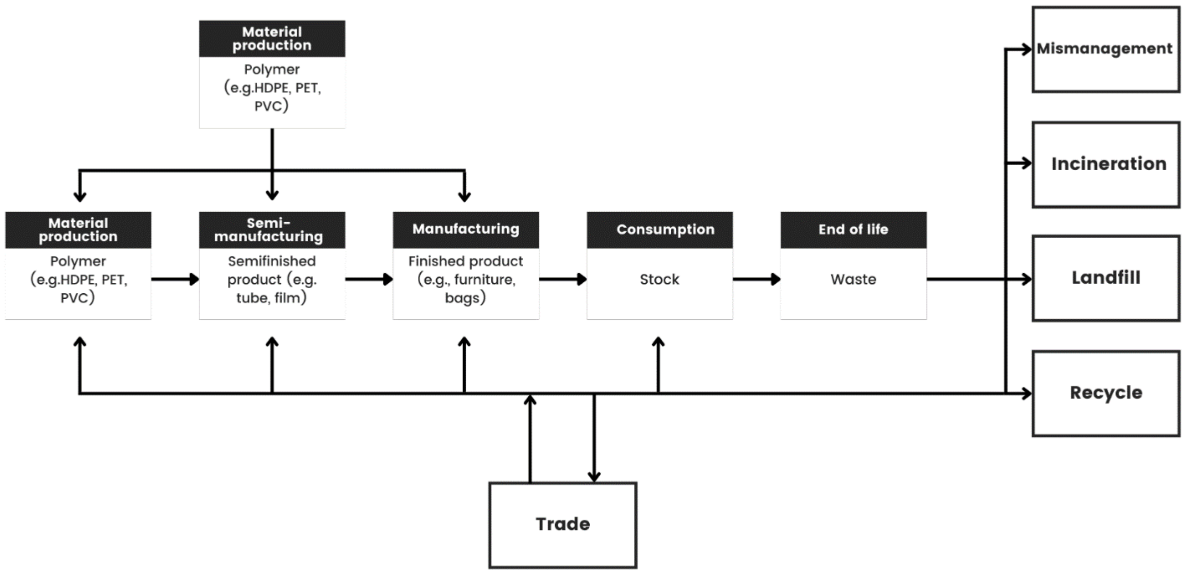


Figure 31. Life Cycle of plastics (Wang, et al, 2021).

The figure above shows the life cycle of plastics:

1. First, polymers are produced. Additives, such as are light stabilizers, antacids, long-infrared radiation blockers, surface tension modifiers, short-infrared radiation blockers, and luminescence additives, are added in polymers to provide additional features for specific applications (Diaz Serrano, 2001).
2. Second, polymers are processed into semi-finished or finished products such as sheets and/or pipes.

3. Next, products ready for consumption are supplied to the agriculture sector. These products can be partially or entirely made of plastics.
4. In the last stage the plastics enter into the waste stream as part of the APW stream where is directly discarded appropriately or mismanaged into the environment. For this reason, it is selection for recovery the key process in order to determine costs on each alternative.

After this process, APW, like any other waste flux, must be managed according to the current EU and Spanish legal framework. In the Thematic Strategy for Prevention and Recycling of Waste in the EU guidelines on Integrated Product Policy and on Sustainable Consumption of Resources an Integrated Sustainable Waste Management scheme is developed and show in the following figure:

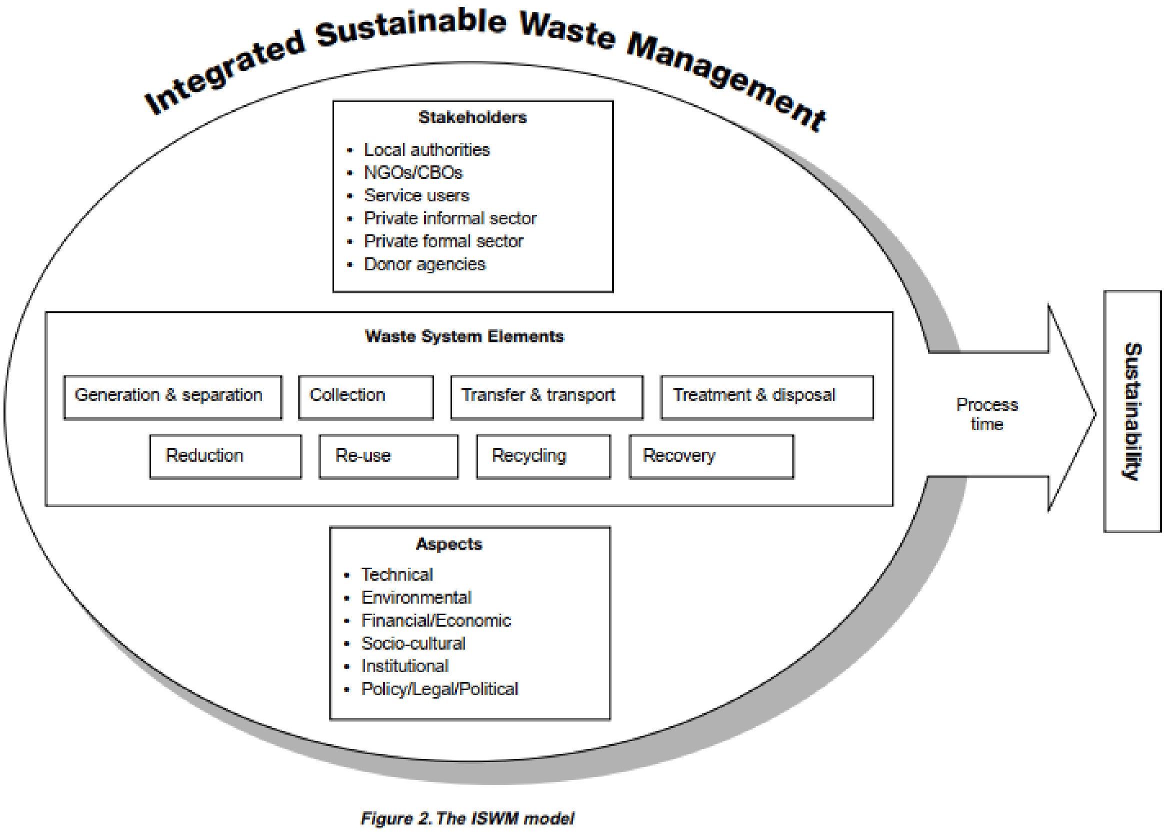


Figure 32. Integrated Sustainable Waste Management. (van de Klundert & Anschutz, 2001)

4.1 Results on legal framework

Law 07/2022, on Residues in its Title 1 highlights the need to prepare waste plans at national, regional (annex VII) and local level, so that, through their integration, the corresponding National Plans can be drawn up (Law 7/2022). Article 12 establishes that it corresponds to the Environmental Ministry to develop strategies, plans and programs on circular economy. Accordingly, in its Articles 14 and 15, establishes a double main objective:

1. The prevention of the production of waste generated through programs
2. The establishment of plans, programs and measures to optimize the environmental management of waste

Applied this double main objective to the APW, the basic management analysis is summarized in the scheme contained in the following table:

Table 3. Basic APW management scheme. (Barres Benlloch, 2007)

Basic APW management scheme	
Impulse for the implementation of the principle of hierarchy in the management of this waste	**Adoption of measures that can contribute to improving the ecological quality of each of the management modalities that make up this scale of priorities**
1. Prevention	Slow down the national production of waste until the current trend is reversed and the generation per unit of product is reduced. Determine the possibilities of waste reduction based on the real possibilities of the sector. Implement the segregation of the different flows.
2. Reuse	Reuse waste when technically possible. Reuse is a valid element to reduce waste generation. Promoting reuse to the extent permitted by the best available techniques should be a priority.
3. Recycling	Recycle recyclable waste
4. Energy recovery	Energetically recover waste that cannot be reused or recycled and has a high energy content The recovery option chosen must be the highest of the technologically possible in the hierarchy scale In the case of plastics, most of its waste can be recovered in some way
5. Elimination	Reduction of the amount of waste destined for landfill disposal Recoverable waste must not be disposed of

Currently there are regional regulations and/or plans that contemplate, to a greater or lesser extent, the APW. They are the following:

Andalusia has Decree 283/1995, of November 21, which approves the Waste Regulation, through which the reduction, selective collection, reuse, recycling and recovery of waste are promoted, as well as such as the elimination of all uncontrolled deposits, in development of Law 7/1994, of May 18, on Environmental Protection.

Decree 218/1999, of October 26, which approves the Master Plan for Urban Waste Management in Andalusia, cites plastic waste derived from agricultural activities, while giving estimates of the generation of APW in padded crops and tunnels of about 180-190 kg/year/ha of normal and light polyethylene, and about 2,400 kg/year/ha of long-lasting polyethylene, in the case of greenhouses.

Decree 104/2000, of March 21, regulates the administrative authorizations of waste recovery and disposal activities and the management of APW. In the latter, manufacturers, distributors and sellers of raw materials, plastics and plastic elements for use in agricultural operations are obliged to participate in management groups that guarantee their correct recovery and elimination, as well as to assume the costs derived from such activity or charging users. Those holders of APW who are not included in a management group will be obliged to comply with the obligations that derived from the corresponding Municipal Ordinance, and to pay the fee for its management, a fee that is already a reality in various municipalities of the Autonomous Community. The aforementioned Decree also establishes that the management of this waste corresponds to the municipalities in whose municipality it is generated, and these may sign agreements with the authorized management groups, in order to entrust the operations of collection, transport, storage, recycling, recovery and disposal of this waste.

RD 653/2003, on waste incineration, transposes Directive 2000/76/EC. This sets the framework for recovering APW in the specific thermal treatment plants for waste, in which the heat of the gases generated in combustion is used.

Biodegradable plastics used in agriculture must comply with the European standard EN 13432. Nevertheless, effective biodegradability of these materials may not be reached within the foreseen period, therefore, management or landfilling until its final degradation should be taken into account.

4.2 Results on field data

A total amount of 1789 objects where detected, sampled and identified according to its type among which 72% were plastic and 21% metal and according to its use 54% of the litter comes from agriculture and 25% of the litter comes from domestic use.

Most of the litter found along the study area originates from agriculture and comes either by direct dumping or from rain transport. Because of physical properties such as size and density, cover macroplastics coming from agriculture are transported, deposited and buried under the gravel in the riverbed by mechanical processes. These plastics include high and low density polyethylene and large pieces of raffia. Vegetation growing along the dry riverbeds promotes smaller litter entanglement in bushes and branches such as plastic bags, plastic nets, ropes, plastic bottles, small piping pieces used for irrigation, pots and plastic seedling pots.

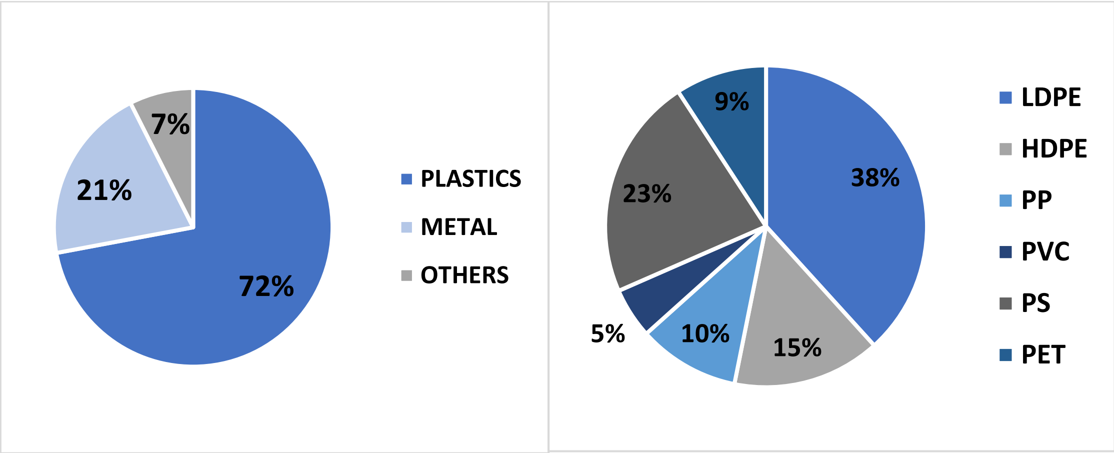


Figure 33. Proportion of plastics found in litter and classification by type.

4.2.1 UAV Imagery

With the image ready for process, each band was defined by setting the wavelength center. The training input outcome is the region of interest polygon and the spectral signatures.

Table 4. Summary of Micasense MX Dual Camera System with their file suffix, bandwidths and wavelengths used in the SCP wavelength input.

Micasense Dual Mx band name	Transparent reflectance blue	Transparent reflectance green	Transparent reflectance red	Transparent reflectance nir	Transparent reflectance red edge
File suffix	1	2	3	4	5
Bandwidth (nm)	32	27	14	57	12
Center wavelength codes (nm)	475	560	668	842	717

Micasense Dual Mx band name	Coastal blue	Transparent reflectance green	Transparent reflectance red edge	Transparent reflectance red edge	Transparent reflectance red edge
File suffix	6	7	8	9	10
Bandwidth (nm)	28	14	16	10	18
Center wavelength codes (nm)	444	531	650	705	740

Following, the three basic steps for supervised classification performed were:

1. Training area selection
2. Signature file generation

4.2.1.1 Training areas selection

For supervised image classification the first step was to create training input samples or Regions of Interest (ROIs). ROIs are either polygons or pixels that the user can create by means of a region growing algorithm designed for selecting homogeneous spectral zones. This was performed either automatically or manually.

The definition data of the wavelength center was made according to specifications and the training file was created (Figure 34). The determination of the RGB options used in the SCP plugin to categorize and better visualize the different cover materials in the mosaic and create regions of interest was performed according to visualization, among which the use of the combinations near the infrared band was found to be more suitable:

1. 7-3-2
2. 5-4-1
3. 9-3-2 and/or 9-4-2
4. 10-3-2 and/or 10-4-2

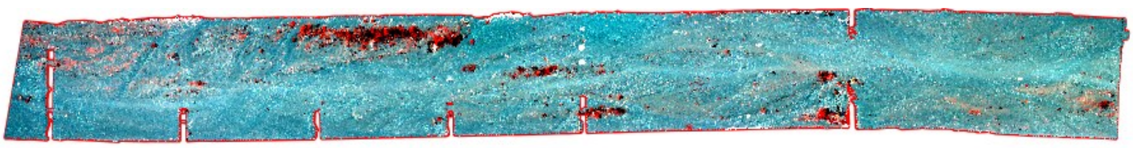
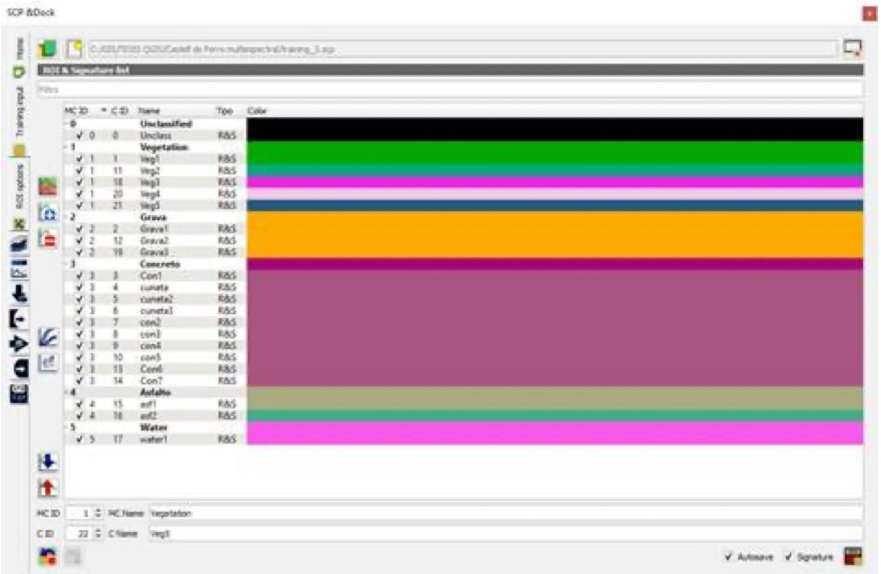


Figure 34. Virtual band set created with RGB composition in the near infrared band.

As a result, a virtual band set with false color created with the RGB combinations to visualize the cover materials. As shown in the previous figure, intense red colors in vegetation help discrimination between plastic waste (in white and black) and soil in (light green/blue). With the regions of interest, each macroclass cover material was created and the materials found in the mosaic were classified according to their origin by means of a polygon and by means of a pointer.

At the beginning, all materials present were covered to assess the SCP plugin performance, ROIs were created. A small distance values of 0.0005 m was set to in order to have more precision in discrimination by using smaller and more homogeneous regions (Figure 35). The materials were classified at pixel scale as listed below:

1. Gravel, using from 1 to 50 gravel samples (individually and jointly)
2. Concrete, classifying up to 50 concrete samples
3. Asphalt, classifying up to 50 types for the same material (this because sometimes when executing the classification there were areas classified as different material, which were corrected and reclassified as asphalt), only 3 were used due to the linear and specific configuration. homogeneous of the material in the figure that is only on the avenues.
4. Vegetation, classifying up to 50 samples as subtypes.
5. Water, some tests were carried out with water classification using the water present in the clarification pond of the treatment plant and others without it to see how the SCP complement behaved.
6. Unclassified category, like the previous one, some tests were carried out configuring a class 0 for unclassified elements in black and others without it.



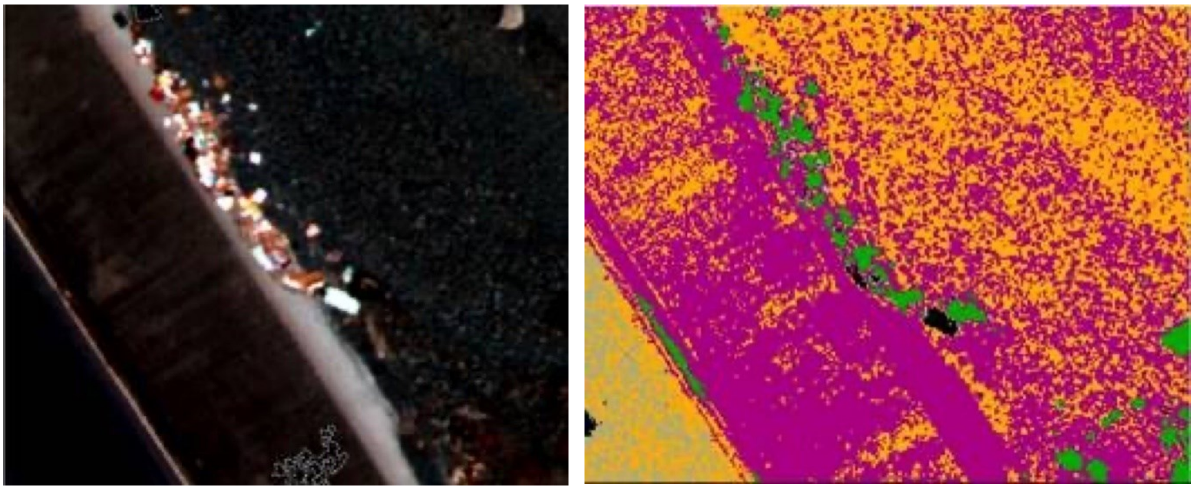


Figure 35. RGB real color vs Regions of Interest showing different cover materials.

4.2.1.2 Spectral analysis and classification

The spectral analysis refers to the import of qualitative and quantitative data of each pixel in the raster image based on its reflectance (Biermann & Clewley, 2020). The different types of litter objects assessed have unique spectral characteristics or signatures. However, some material covers like concrete and asphalt showed resemblances for the spectral angle which brought issues latter with the classification, the similarities observed in reflectance pattern affect different material reflectance discrimination (Figure 36). This could be explained by different cover materials present in the same pixel at a single pixel scale.

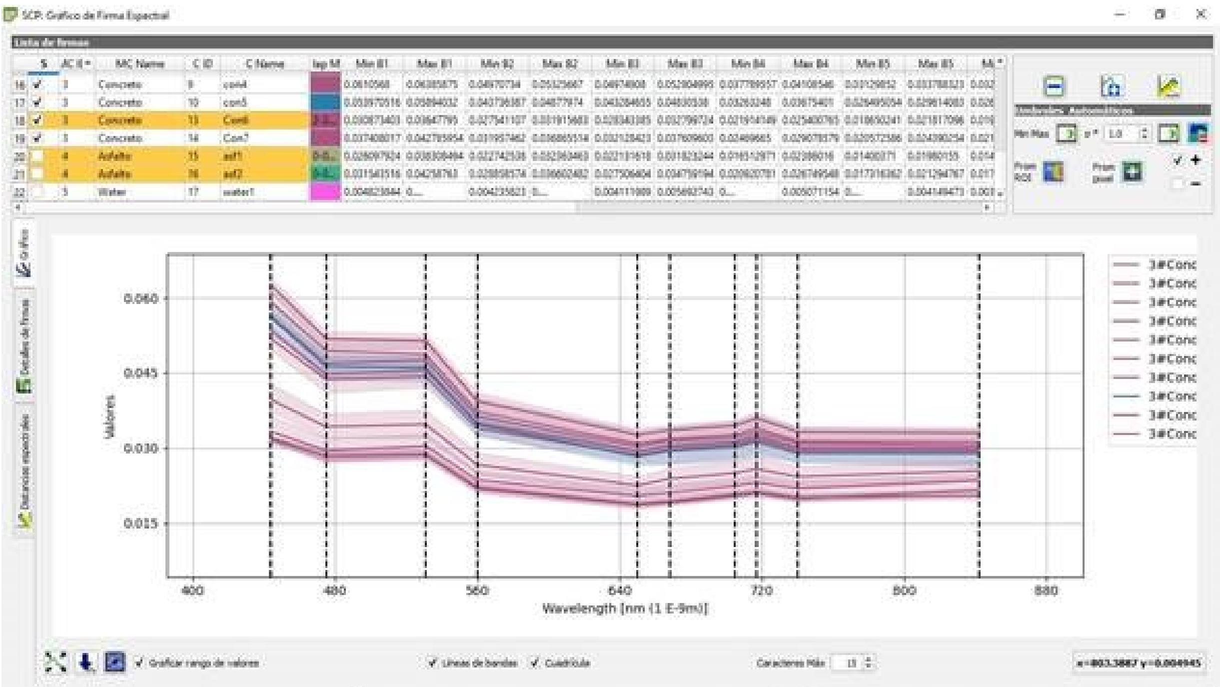


Figure 36. Spectral signatures of concrete and asphalt.

Based on the spectral signatures of the different materials that resulted from Micasense Dual camera set, it was shown that the SCP plugin performance improved with the analysis of fewer materials at a classification assessment. For this reason, it was important to reduce materials only to gravel and vegetation. A mask was created to discard the non-relevant materials leaving only the raster image (Figure 37). In the following figure, the study area is shown after clipping non relevant areas (top), creating the boundaries sector (middle) and virtual raster creation with false colors for ease of identification before creation of ROIs.

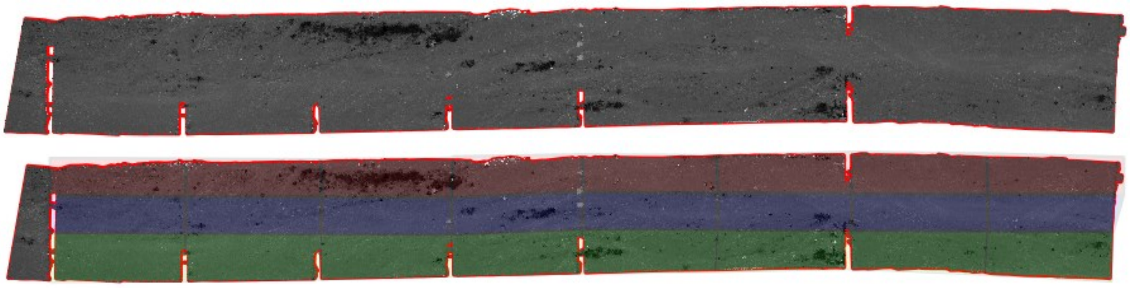


Figure 37. Study area with clipped raster.

A second approach was used with only types of classification performed: vegetation and soil. Plastics were indirectly detected as unclassified. Different classification algorithms were tested for this action:

1. Maximum likelihood
2. Minimum-distance
3. Spectral angle mapping

On this stage of the process the SCP plugin however, presented some classification errors; the trend was to classify the waste as concrete or sometimes even with vegetation because of spectral similarities. Vegetation reflected light in the green (531nm) and red edge (740-842nm) bands, gravel on the other side reflected light better on the blue band (444-475 nm). According to (Martínez-Vicente, 2019) plastics reflectance is out of reach for the sensors used thus, it was key to perform a reverse classification meaning all materials were classified and only then the classification was performed with the plugin, leaving litter as unclassified.

Samples were selected for each land cover class. Subsequently, the process was repeated adding training sites representative of different materials until the materials were covered in the entire image. Finally, for each ROI an average spectral signature is created as an output. After several test for creating single ROIs for each class a classification preview was performed to assess the results of the classification without running the classification of the whole image (Figure 38). In this step, the classification algorithm and the size of the preview can be changed as well to assess its performance.

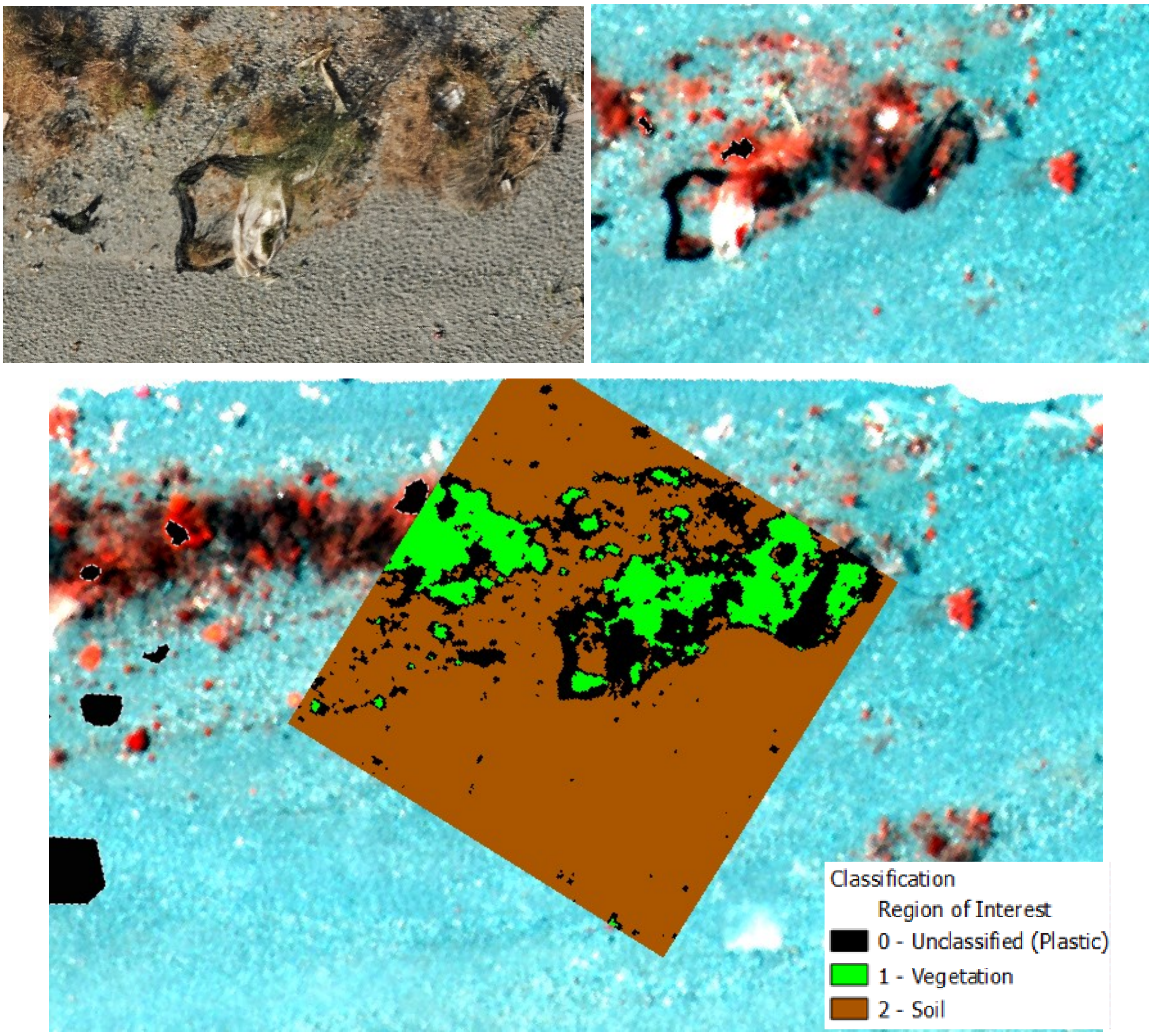


Figure 38. RGB image, Virtual Band Set image and classification preview are shown.

It is important to highlight that on this step if any errors were identified more regions of interest were added or in some cases the whole process was repeated to reduce the errors and improve classification process. For this conditions the maximum likelihood algorithm was changed to minimum distance, which was the classification algorithm that better results delivered. Each one of the macroplastics that was identified with data record and picture on the field survey was located on the mosaic picture for validation in the classification output.

4.2.1.3 Generate signature file

The software then used the ROIs and applied them to the entire image for classification. Since every object has its own composition and reflects light in a unique way this means that each composition has its own spectral signature. This is the objects "fingerprint". Once all the ROIs for each class were created within a macroclass, al the spectral signatures were merged for each macroclass either vegetation or soil. This action aimed to avoid previous issues with "spectral mixing" between different macroclasses (Figure 39). Once the project was completed, a signature file was created, which stored all training samples spectral information. On the following picture each spectral signature is shown for soil and vegetation, note that each material has some unique reflectance spectra. While vegetation peaks reflectance in the green it absorbs blue and red reflecting more green and showing it on its color (Figures 39 & 40). Soil on the other side has different spectral characteristics bases on its moisture content, organic content, texture, structure and iron oxide content taking into account that all these factors are interrelated between each other (e.g. proportion of sand, silt and clay influences texture and structure and its related on its ability to hold water, this means moisture). In the following figure, the x axis shows the spectral range in the visible blue light to the near infrared (NIR) at 842 nm, on the y axis, the reflectance is shown dimensionless.

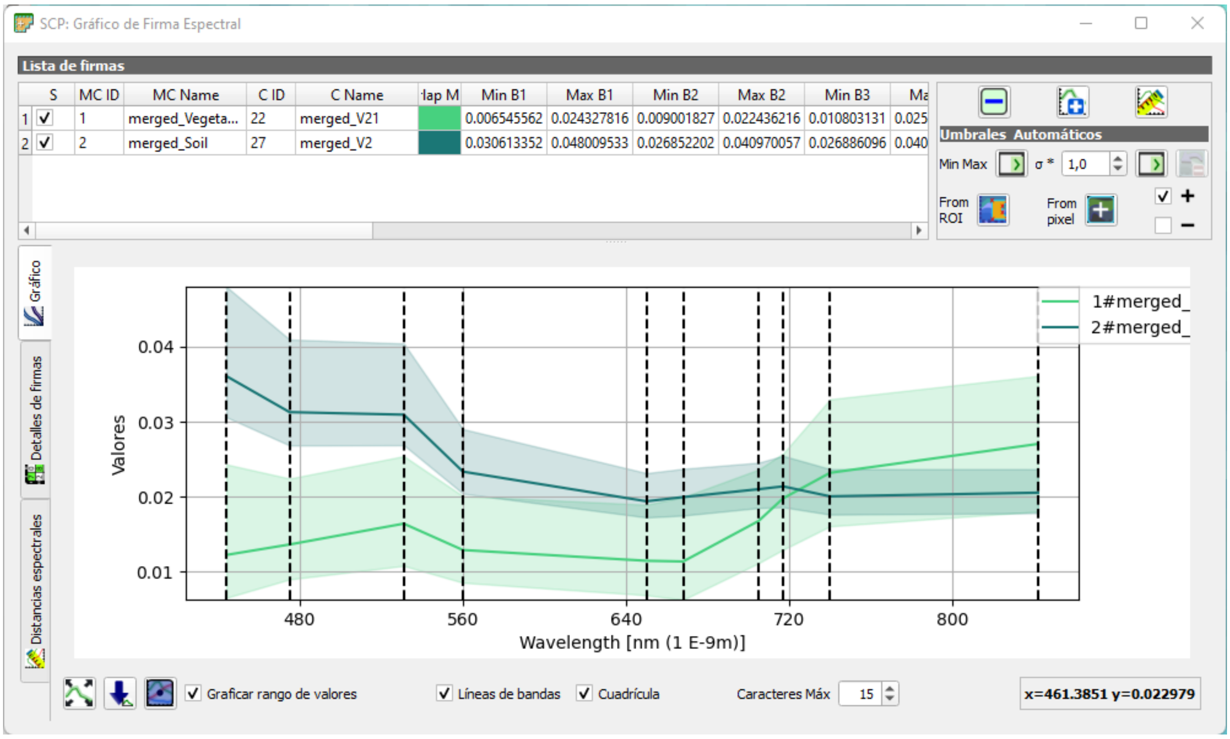


Figure 39. Mean spectral signatures of merged vegetation samples and merged soil samples.

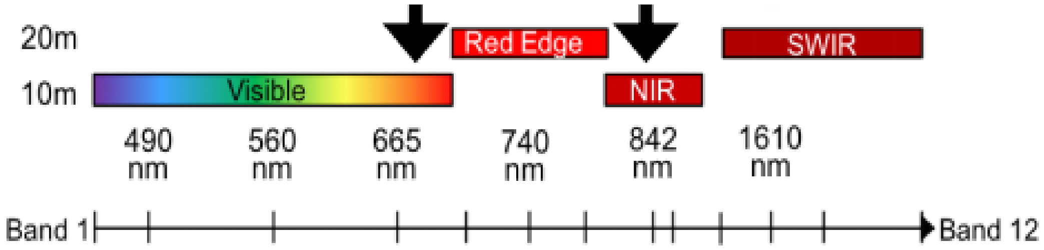


Figure 40. Visible, red edge, Near Infrared and Short Wave Infrared wavebands for reference. (Richards, 2022)

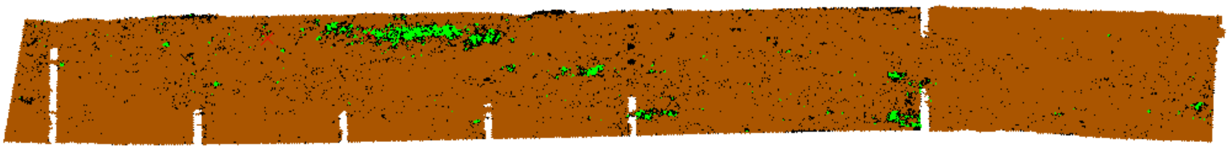


Figure 41. Final classification raster.

Classification previews were performed until the success rate of each classification in regards to ground trothing was calculated and results were satisfying and the plugin used the signature file to run a classification output.

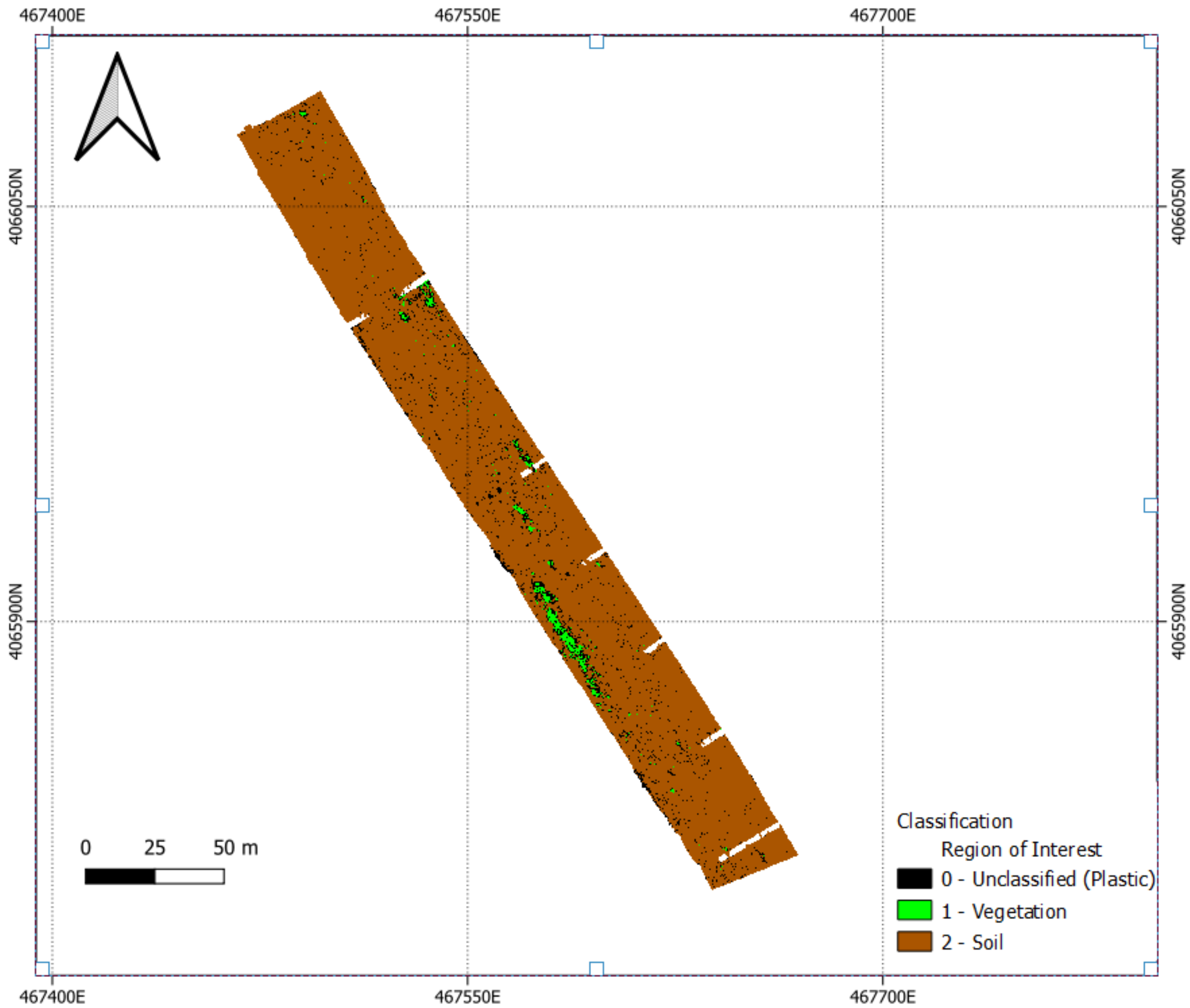


Figure 42. Final classification thematic map.

4.2.1.4 Ground truthing

During the assessment of each object on the study area it was demonstrated that the images obtained and georeferenced the multispectral and RGB flight and the images in the waypoints of the Wikiloc application had several differences on their location. For this reason, several tests were performed to georeference the RGB image with the multispectral image and buffer zones were set up to match the location of the same objects in the csv file output in the layer. Since this operation was unsuccessful, visual comparison was still allowed and performed for macroplastics identification.

Afterwards, unidentified objects were colored white leaving the rest in black to ease assessment. Then, the image processing raster file was transformed into a vector point type layer file by transforming the pixels to points. The objective was to obtain a layer in which geoprocessing analysis could be performed. The result was a point cloud representing the unclassified objects which was later used to intersect. The output resulted in 111 polygons across the red, blue and green delimited sectors and saved as a vector layer. With this layer, geoprocessing was successfully performed to intersect the points that represented the unclassified pixels obtained in the previous procedure and compare these data to verify the efficiency of the tool. Finally, a total of 4,469 points was obtained for each one of the 111 agriculture plastics previously identified on ground.

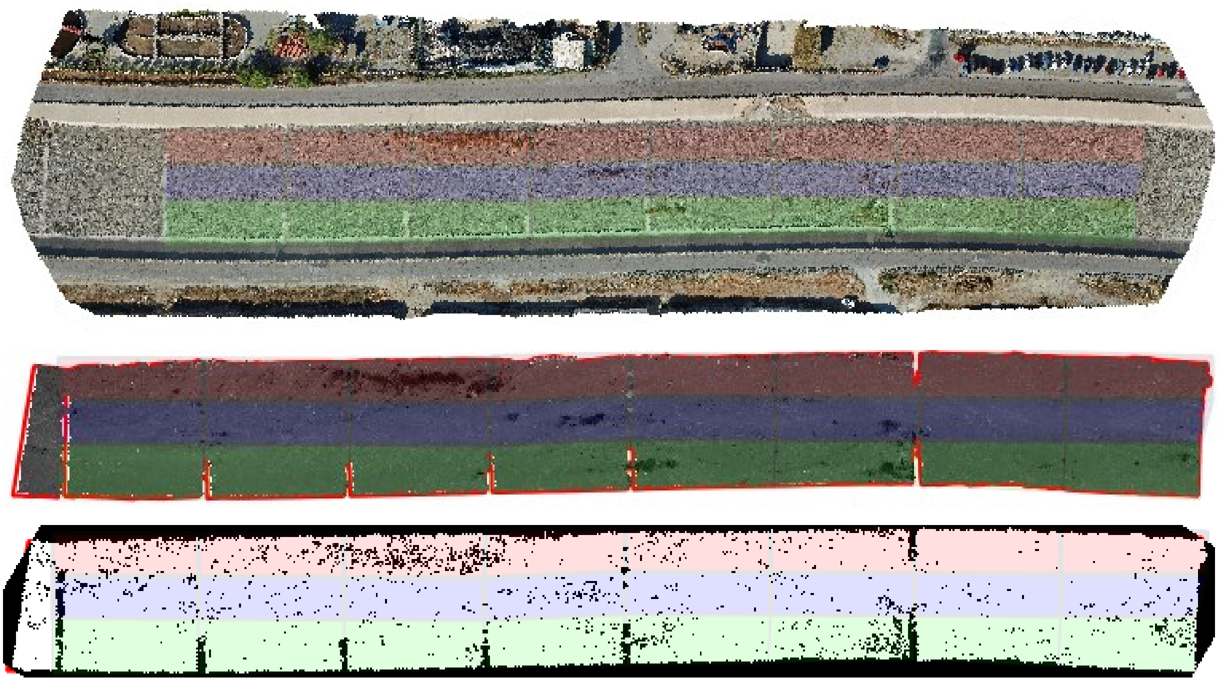


Figure 43. RGB, multispectral and binary classification composite. The orthomosaic was captured on September 2, 2021.

The statistical analysis of the raster obtained initially with the unidentified objects was carried out and a total of 240,768 was recorded. Unidentified pixels covering an area of 1,221.93 m2 out of a total of 2,188,300 pixels and a total area of 11,105.93 m2 representing 11.00%, the area obtained only for the polygons drawn for large plastics was 27.98 m2.

The Semiautomatic Classification Plugin –SCP- performs a calculation for the classification matrix through the Post-processing tab. This process was performed for the classification raster image. The output was a classification report (Figure 44) showing that for macroclass 0 (APW and litter), the area covered in the study research boundaries was 543.85 square meters (m2) covering 5.05% of the area, for macroclass number 1, an area of 145.81 square meters (m2) was covered by vegetation representing 1.35% of the total area and for macroclass 2, an area of 10,085.45 square meters (m2) was covered for soil representing 93.60% of the total area.

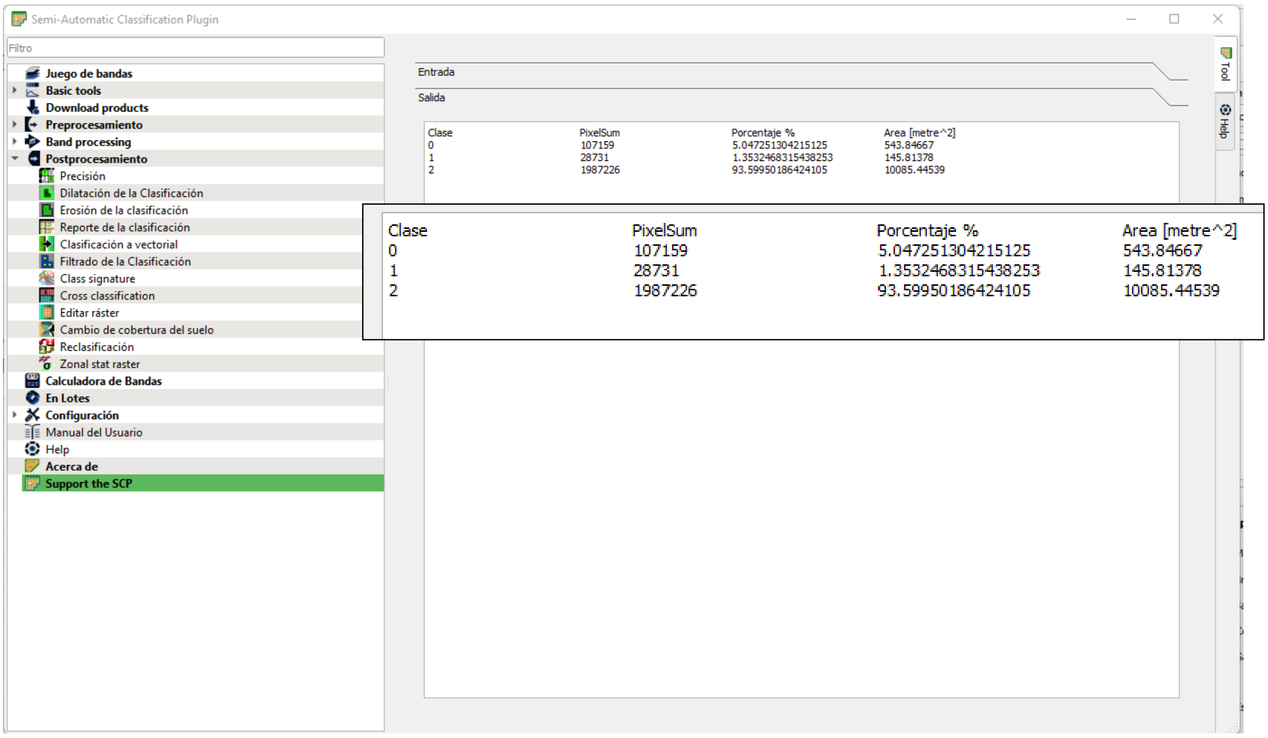


Figure 44. Classification report.

4.2.1.5 Accuracy assessment of classification

The accuracy assessment of the macroclasses was crucial to understand how well the classification was performed in terms of quality and to decide whether to correct errors, primarily if this data is going to be used for scientific assessment that could be for example as a training for machine learning training data. The input was the classification raster with two classified classes (soil and vegetation) that was used to calculate the area proportion for each macroclass.

The stratified random sample used the SCP tool Multiple ROI creation. This tool allowed for the random creation of point coordinates according to the sample scheme previously defined and the points classified manually according to each macroclass on the raw multispectral data. Creating a Virtual Band Raster with the previous waveband set according to the wavelength center of each band was a key point for better identification results. Then, the main issue was to use value as No data checked to exclude the no data values from the calculation.

Finally, results showed that the semi-automatic classification precision for vegetation and soil was acceptable (overall accuracy~95% of success) and a Kappa Cohen value of 0.59 following the methodology proposed by (Olofsson, et al, 2014). Finally, the confusion matrix brought an idea of the actual ground truth classes and their comparison with classified data. A possible explanation for the overall accuracy value is that because of the size of each pixel it allows to have mixed classes within it (Figure 45). This value is a parameter that provides an estimate of the accuracy of the classification.

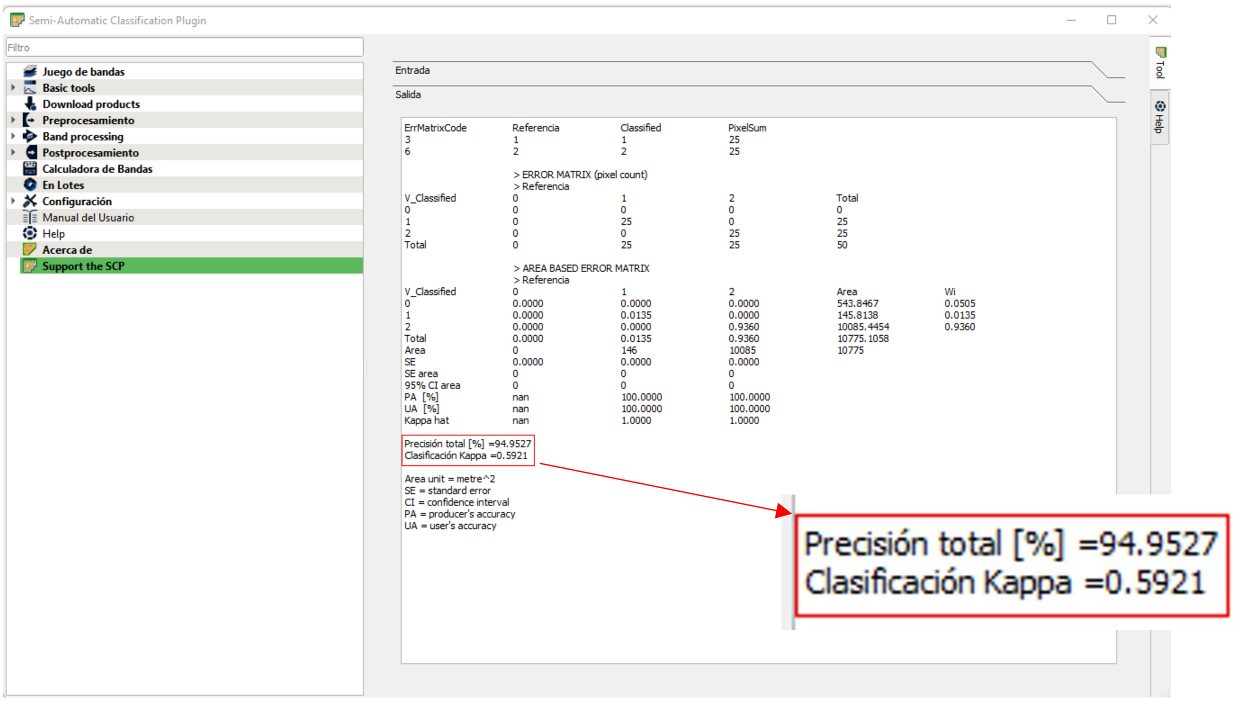


Figure 45. Error matrix of the classification using the Minimum Distance algorithm.

5 Discussion

As shown on figure 31. Life of plastics, the economic cycle of plastics considers APW as a product to be used according to its type and quality among other factors for its adequate management. For the waste generation, actions must be prioritized that involve its reintroduction into the economic cycle accordingly. Prevention should be considered as a first step, reducing the use of the product and reuse subsequently. Reuse reduces APW generation to its extent and should be considered a priority among other solutions. Subsequently, recycling and energy recovery should be assessed and, finally, safe disposal by dumping the rest of the waste that cannot be introduced into the economic cycle would be the last possibility. The disposal amounts must be the absolute minimum; strictly speaking, only waste that is neither reusable, nor recyclable, nor energy recoverable, should be disposed in this way.

To establish an APW management model such as shown on figure 32, it is necessary an approximation to the data and estimates on the generation of APW, for this purpose, first, to characterize what types of waste are included under the name of "Agricultural Plastic Waste". Since there is no precise legal definition of this term, neither in Spain nor in the EU, APW is considered to be those plastic waste produced in agricultural and/or livestock activities, including aquaculture, except for packaging waste.

There are several management models. Therefore, corresponds to the competent local authorities to select and establish a model whose principles guarantees the achievement of the objectives pursued. In all these declarations and strategic documents of the EU, emphasis is placed on prioritization and the need to dissociate waste production from economic growth and achieve a global reduction in its volume through prevention.

5.1 Policy of sustainable development and saving of resources and prevention and management of APW

5.1.1 Management

Since agricultural practices generate huge amounts of plastic waste that need appropriate collection and disposal. An integral framework proposal should aim to manage plastic residues from the source at the beginning of the cycle by reducing plastic packaging and containers, increase efficiency of waste recycling by increasing the effectiveness of recycling actions in those areas where its use cannot be avoided and measure inputs and outputs. Finally, awareness must be promoted within each farm community as in the case of Castell de Ferro. The main objective should be to acquire sustainable consumption habits and environmental responsibility. From a broad sense the following sections should be addressed:

- Citizen awareness and education
- Data
- Systems and technologies for the prevention and management of APW
- Legal framework for APW
- Economic instruments

5.1.2 Citizen awareness and prevention policies and management of APW

Citizen awareness and social pedagogy in its broadest interpretation are factors of utmost importance to obtain the collaboration of the population in the implementation of APW management; education programs must be included since it is considered necessary to introduce outreach and social pedagogy programs aimed at motivating the population to create environmental awareness and responsibility in younger generations which is essential to achieve better prevention and management of residues. Policies awareness on environmental impacts of consumer choices through formal or informal means such as schools or cleaning campaigns education is a long-term strategy to reduce consumption of plastics (Prata, et al, 2019).

To the above must be added the essential promotion of content related to waste in elementary and primary education programs, as well as the adaptation of training programs for specialists in the various APW management activities (Geok Yeo, et al, 2015).

5.1.3 Data on self-sufficiency and proximity of APW management infrastructures

The treatment and recycling capacity of plastic facilities should comply to the APW volume generated. Therefore, update and expansion of current facilities capacities are measures to be prioritized to ensure recycling of waste in the short and medium term. However, if there is an infrastructure deficit it only will be quantifiable with verified statistical data of its production.

In the event that the use of biodegradable APW is extended, the possible need for temporary landfills for their waste should be assessed bearing in mind a cost-benefit study and accordance with land use planning.

5.1.4 Systems and technologies for the prevention and management of APW

Waste materials should be separated at source as much as possible to improve the quality of materials for reuse and recycling, to reduce energy use in collection and to improve working conditions, monitoring types and amounts of plastic at all stages. Separation at source, reuse and recycling take an important place in the waste management hierarchy. On another hand, the use of technologies such as monitoring of waste flows and hot spots with the aid of UAV systems for APW illegal abandonment can directly impact on plastic waste dumping on the sea. Measure of results is a key factor on improving the management system.

5.1.4.1 Prevention

It is important to develop RDI in order to develop alternatives in certain processes and compare life cycles along the chain value of certain products. Regarding EPR, APW should be managed as in the case of bottles starting in large generators of the product such as the case of SCP cooperative or in large companies on their business models promoting APW prevention. In the case of biodegradable polymers, it is necessary to assess the lifespan and degree of decomposition of different polymers as the presence of phytosanitary products and possible soil contamination and aquifers can impact the ecosystem on the long term.

Recycling promotion requires conditioning of APW production and consumption, this actions can be accomplished with regulation and economic incentives. Regulation should be assessed bearing in mind that is inconsistent with free-market economy philosophy.

5.1.4.2 Reuse

Reuse is management second hierarchy option, since it’s a valid option in reducing APW generation, a shift towards reuse is still in its early stages, but there is growing ambition from the public and the private sector to advance it as an alternative to single-use.

5.1.4.3 Recycling

A second life is found for APW through recycling. Management of the APW through recycling allows the recovery of raw materials. For this purpose, waste needs to be cleaned, crushed and reprocessed (Briassoulis, Hiskakis, & Babou, 2013).

Regarding its impregnation by pollutants, some studies indicate that the amount of pesticides in these residues is significant, nevertheless, exposure to hazardous chemicals by waste collectors must be considered as well (Beriot, 2022). A factor of certain phytosanitary importance in some Agriculture Plastic Waste may be the presence of pathogenic agents. For this reason, it is necessary to perform characterization and quantification of other residues that can accompany the APW (like soil residues, organic matter, phytosanitary products, fertilizers, others) which will include an additional cost. Nevertheless, the notable increase in the price of oil, the main fossil raw material for polymers, configures a new scenario and, in principle, a more promising future for pellets from recycled material.

Chemical recycling of greenhouse and mulch APW remains as a potential alternative to the conventional energy valorization of some highly degraded APW for which current techniques recycling is not possible.

5.1.4.4 Energy recovery

In Spain, energy recovery experiences have been developed for the combustion of polyethylene films for greenhouse covers in pulverized coal power plants, and for use as auxiliary fuel in pulverized coal power plants. However, new energy policy transition into renewables limits its use such as the case of the tests that were carried out in Litoral de Carboneras, a thermal power plant located in Almeria which started closing on 2021 (Simon, 2014) (Fenoy, 2021). Therefore, authorities need to sanction waste valorize energetically in a way that industrial plants are able to comply with its provisions.

Parameters such as the energy content of the waste, the efficiency of the energy recovery process, the existence of a real energy demand, and the substitution of energy from non-renewable fossil fuels for that from waste, are elements to take into account. Studies aimed at searching for blending mixtures and meet technical and ecological conditions for their energy recovery need to be performed.

Recent incorporation of new energy recovery technologies bring a new insight on using mixtures in cogeneration plants, can also modify the real possibilities of managing APW through this management channel (Petrikovicova, 2021).

5.1.4.5 Elimination

It is necessary to re-incorporate the materials contained in the APW that are susceptible to this second treatment to the productive chains and consider hazardous chemicals attached due to use of pesticides in biopolymers bearing in mind replacing the most toxic and dangerous substances with less harmful ones, whenever possible. (Beriot, 2022). This practice will reduce the consumption of virgin materials, especially non-renewable ones (Steinmetz, et al, 2016).

5.1.5 Legal framework discussion

Existing legislation lacks impact to reduce APW. To overcome current governance problems, economic policy instruments should be introduced. The establishment of a financing model should be analyzed, based on the cooperation and shared responsibility of all the stakeholders involved in the APW management, establishing economic instruments to achieve improvements on its prevention and control.

Article 20 2) of Law 07/2022, on Waste, contains the obligation to generate, prepare and supply basic data on waste produced and managed. However, this does not refer to agroplastics. Furthermore, it seems necessary to address the preparation of a future National Inventory or Statistical Information System on the generation and management of APW for each location i.e. Autonomous Community or municipality, which will contribute to adequately sizing and solving the problem of APW.

According to Cicloagro/Cicloplast, APW generation can be accounted by correlating and cross-studying its consumption by means of an average use lifespan between 1 and 3 years. Based on this fact, traceability of materials plays a key factor along the value chain; from supply to use.

The current recyclability of film has an important limitation: the presence of soil in plastic waste can reach levels of up to 70% of the gross weight and profuse degradation due to continued exposure to the sun. The plastic used for mulching is the least recyclable, while that used for cover in tunnels and greenhouses is recyclable by more than 80%. The greatest recyclability potential occurs in LDPE films and tubes, HDPE tubes and PVC tubes.

The regulations and provisions approved on waste management, on Integrated Pollution Prevention and Control and regulation of waste disposal by landfill must be taken into account in order to comply with the water, soil and atmosphere emission standards for energy recovery facilities.

- December 27 Royal Decree 1481/2001
- RD 653/2003, of May 30, on waste incineration and Law 16/2002,

APW generation in Spain from crop sheet must be taken into account to ensure waste and production match capacity accordingly the current recycling infrastructures.

The regulations on the forms of production in organic farming, by establishing pest and disease control practices that dispense or reduce the use of synthetic chemical products, are based on alternative techniques such as the use of low-quality cover materials, degradable, manageable and easy to use, such as plastics (Sullivan, 2011; Gu Lee, et al, 2021).

There is no legal definition to the term Agriculture Plastic Waste including biodegradable polymers demarcation. The images and results performed on fieldwork demonstrate that despite the existence of plastic waste regulations, in the case of agriculture on loads of plastic are still being dumped into marine bodies on the coast of Spain. Among the causes, there is an obvious lack of specific regulation that addresses a responsible specific authority with clear responsibilities as well as the need of plans with adequate facilities projected for the collection, transfer and final disposal of APW considering its location and the amount of waste generated in response to the existing farm censal data. At the same time economic incentives such as banning single use plastic products, higher rates for plastic products and alternative sustainable solutions should be taken into account in plans with specific objectives ensuring measures are assessed and thus having feedback. The waste regulations establish an essential principle on responsibility in the generation of waste in general, which is applicable to the generation of the flow of APW typified in code 02 01 04 of the LoW (Briassoulis, et al, 2010).

5.1.5.1 Collective Systems of Extended Producer Responsibility (SCRAP)

The main point of a law addressing APW is delimiting the scope of this obligations, establishing the responsibility requirements and the procedure to meet them, to which, through the corresponding regulatory development, producers may be subject in designing and producing their products and subsequently managing the waste derived from its production, either individually or through collective systems to comply with the standards established

This will have an impact for the entire value chain as it will be necessary for companies to improve and enhance their products containing recycled material to allow its recycling. This requires a regulation to implement this measures thus, establishing system of Extended Producer Responsibility (individual or collective) for the APW sector.

5.1.5.2 Circular economy and the link with the Sustainable Development Goals

The law is contradicted by excluding from its scope on one hand, the plastics used in greenhouses and on the other by regulating how single-use plastics should be eliminated in the case of mulch plastics for example (reuse is complicated by the conditions in which it is left after use).

This Law aimed to promote a circular and low-carbon economy in Spain, going through the current regulations on waste and contaminated soils to meet the new objectives established in the community waste directives with specific objectives by reducing the waste produced by 13% in 2025 and 15% in 2025 compared to the weight generated in 2010, as well as those derived from the single use plastics in line with the Spanish Circular Economy Strategy known as Spain Circular 2030 linking economic growth and improving environment by reducing its negative impacts and therefore improving human health at the end of the chain as a result (MITECO, 2021).

However, to reach the desired objectives, first it is necessary to focus the approach from a comprehensive manner which cannot be accomplished without taking into account APW with specific targets such as increasing separation of plastics according to its properties for reuse and recycling with measureable targets within established timeframes.

The challenge will be to include within it more than 900,000 farms, 12 million hectares of arable and permanent and woody crops. The organization will be key to involving large investments within the sector to manage plastic material as waste and how and when farmers will be able to assume them in a crisis scenario or in this case plastic producers. That is why an official interpretation should be made clarifying whether greenhouse plastics are also waste managed within the farm itself. In a similar manner, Autonomous Communities must intervene assuming its corresponding responsibilities, however, it is necessary that regulations include relevant stakeholders to take into account agriculture economy reality factors, which is different between regions (MITECO, 2021; Montero Montero, 2022).

5.1.6 Economic instruments

It is important to highlight that solutions are beyond the 6Rs: Rethink, Refuse, Reduce, Reuse, Recycle, Repair. This means that while certain actions such as elimination of single plastic use and implement actions at local, national and international level to drastically reduce its production, financing mechanisms to bind plastic producers with plastic elimination, monitoring, evaluation and feedback need to be implemented at local and national levels. At an international level, standards must be created to bind this actions to plastic products trade. Since it is necessary to minimize the consumption of resources, especially non-renewable ones, in the production of Agriculture Plastics and in the management of APW, actions to encourage this type of policy should be highlighted such as secondary markets promotion for recycled materials and products.

Selective taxation should address virgin materials and all non-recycled products and incentives should address reuse of secondary materials in order to promote a demand for reuse and recyclable products to encourage circular economy. However economic research should assess each alternative to be consistent with waste hierarchy.

Financial compensation for collection and management of APW could be performed through agreements or legal instruments, rates to cover the expenses on its management for autonomous communities.

5.1.6.1 Fiscal measures to encourage the circular economy

As for the extended responsibility of the waste producer, the regulatory proposal will need to revise the framework regulation in coherence with community regulations and specifying the obligations that can be imposed by Royal Decree on producers, looking forward to review its application on agricultural plastics within the timeframe established. Finally, the fiscal measures must be displayed to public and consumers to raise awareness and ensure traceability of funding.

5.1.7 Market research

The current market plastic recycling used in agriculture finds significant competition in industrial and construction plastic waste, for it has better characteristics than agricultural waste. Nevertheless, residual PE plastic from crop protection sheets, which is vulnerable to uncontrolled incineration causing negative environmental impact. An important business opportunity could be found in recycling due to the recent rise in the price of oil (due to several factors) which as a result impacts the price of virgin pellets for the manufacture of plastic products and, since many of these are manufactured by mixing first-use material with that from the recycling, there is a strong demand, not only for recycled primary product, granules or agglomerate, but even for simply pressed and packed residual plastic sheet (Castillo-Díaz, et al, 2021).

The consequence of all this is that it seems to reduce the uncontrolled dumping or abandonment of residual PE sheet, although this happens in the case of thick plastic, thinner plastic, even though it does not have as high demand due to the complexity in washing impurities attached to it which causes obstruction of the filters in the pelleting process, making recycling less economically viable, however, this plastic is less degraded by radiation.

It is necessary to propose economic, technical and legislative aid lines for those research, development and innovation programs or development of ideas aimed at opening markets to products or goods made with recycled plastics (Galati & Scalenghe, 2021).The research and development of new technologies are decisive instruments for the application of the Best Available Techniques, the consequent reduction in the generation of APW and improvement of its management, and the search for new uses of materials from plastic waste (Swain, et al, 2004; Rujnic-Sokele & Pilipovic, 2017; Picuno, 2014).

Methodological instruments need to follow APW management evolution. Technical standards that regulate certain forms of production in agriculture must be taken into account, such as those of integrated production contained in Royal Decree 1201/2002, of November 20, which establish the express prohibition of the abandonment of plastic remains inside or on the plot's borders (Galati & Scalenghe, 2021; Matter, et al, 2015).

Since regulation establishes physical methods as mandatory practices in the control of pests and diseases and chemical control methods are mandatory in the control of pests and diseases, it is also possible to expect a trend towards an increase in the use of practices such as soil solarization, biofumigation and biosolarization, which can contribute to increasing the use of polymer sheets in new uses and plots, in geographical areas in which plastics had not previously been used for these purposes.

5.1.8 Field data

Among the main observations, agriculture source plastics were predominant on the study area. The proportions share some similarities with the results published in the European data results, the most abundant type of plastic was Polyethylene (PE) in both forms, followed by Polypropylene (PP) showing similarities with the analysis results of European plastics production, demand and waste data report (PlasticsEurope, 2020).

One major advantage of this activity is that data collection can be performed by anyone as there is no need of highly qualified or certified personal but can be performed by untrained personal just having a mobile phone with the application downloaded as the application is user friendly. On the other side, mobile phones lack accuracy, for this reason if precision is required it is necessary to make use of higher precision equipment such as GPS and/or drones. However, this activity demonstrated to be useful as a preliminary approach for detecting and registering litter hotspots in previously studied areas before performing actions that deliver more accurate results but imply more use of resources such as high skilled human resource, drone equipment, transport and even flight permits to perform data collection.

Another fact is that an application could be created to perform this specific activity. This can be rewarding in terms bringing additional insights and longer-term plastic hotspot mapping on rural areas in terms of variation in inputs and transport dynamics. This was demonstrated with untrained citizens in the Netherlands and Malaysia with similar estimates of plastic abundance, polymer categories and spatial and temporal variation (Tasseron, et al, 2020)

To sum up, this first activity was a simple but very important step as it can be useful either as a preliminary approach for hotspot plastic litter detection and monitoring or it can be used as an assisting tool for validating data with more accurate and technical approaches such as drone surveying. Finally, results can be used to disseminate among relevant stakeholders including citizens and decision makers not only to increase awareness but also for collecting data, implement cleaning campaigns and further higher level interventions.

5.1.9 Monitoring tools for effective APW survey

GIS systems need to be included as tools to measure success outputs of alternatives selected. The lack of data and monitoring mentioned above shows the need to be taken into account in planning and measuring inputs and outputs as well as the convenience of a correct management of plastic waste in those cases (Hopewell & Kosior, 2009).

The proposed tool showed good results for agriculture plastic assessment at the dry riverbeds in Castell de Ferro with success performance over 95%. It was demonstrated that the use of UAV systems in synergy with GIS free software have a great potential for cost effective and easily plastic monitoring tool on dry riverbeds at a small-scale. In addition, the equipment used had an effective performance macroplastic detection.

Planned future activities must considerate the factors mentioned above and a previous characterization for each kind of plastic litter reflectance should be performed to calibrate and validate the sensors that are going to be used on field. Development of algorithms for monitoring macroplastics under these conditions would increase time efficiency in GIS classification software and a cloud database can be developed for further data analysis and feedback. These steps can make a difference in the success of this synergy tool which can deliver important data in the assessment for developing future strategic approach policies in plastic waste management at the source.

6 Conclusions

In general, producers must design and manufacture reusable and recyclable agriculture plastics. In this regard, economic and financial incentives on RDI programs on APW need to be developed in order to avoid or reduce to the extent hazardous substances use on plastic manufacture.

Farmers have to be informed about APW characteristics and recovery potential for reuse or recycling according to its type.

Selective APW collection schemes planning and implementation need to be practical and facilitate its delivery to farmers at no cost to ensure APW transport to classification and recovery facilities in collaboration with distributors. Responsible authorities need to promote agreements between the administration and the private sector.

Agricultural plastic waste management has an economic potential to avoid mismanagement by farmers in the case of abandonment and illegal dumping. Therefore, there is a duty be environmentally responsible in terms of waste prevention and management. For this purpose, actions that identify, promote, disseminate and contribute APW recover and increase its safe use should be implemented. This will improve life quality and increase competitiveness of the sector and increase appreciation of local products and services, protect natural and cultural resources.

Monitoring plastics with the use of GIS systems showed good results for agriculture plastic assessment at the study area with success performance over 95%. It was demonstrated that the use of UAV systems working together with GIS free software have a great potential for cost effective and easily plastic monitoring tool on dry riverbeds at a small-scale. In addition, the equipment used had an effective performance macroplastic detection.

Since passive methods that use NIR and/or SWIR bandwidths have potential for the detection of plastic waste because their spectral reflectance is in a range of 1215 - 1732 nm according to (Garaba, 2018), it is necessary to emphasize that the MICASENSE Mx Red & Blue multispectral camera used is not within this range and therefore the detection of plastic-type residues cannot be done directly. It is for this reason that it was necessary to carry out the indirect analysis, meaning that plastic detection was done in a reverse mode, this was, identifying all the materials that were not plastic leaving everything that was not identified as possible plastics through SCP.

The results obtained are intended to contribute to develop plastic waste resource management monitoring strategies and showed positive feedback. However, if higher success rates are desired, could be increased by further performing the proposed procedure with plastic waveband range sensors. For plastic types reference, the USGS library could be used.

The combined use of Unmanned Aerial Systems (UAS) imaging and field surveillance provided significant advantages and successful results allowing plastic detection with georeferencing on site. However, a series of parameters affecting the performance were identified. Spectral mixing creates noise and delivers false positives when performing this kind of assessment. This can be reduced creating more Regions of Interest (ROIs) and merge according to cover type hence, it is important to take into account time and efficiency. Secondly, bandwidth reach with cameras was a key limitation, so sensors equipped with SWIR bandwidths should be the next step. Another important factor was the geographic precision of waypoint pictures in the CSV file which presented some limitations when comparing the results with the multispectral and RGB image. This can be solved using precision GPS for this action.

Other factors such as aging and weathering of plastics impact on its reflectance and creates errors due to spectral similarities by the SCP tool. Nevertheless, it's important to highlight again that every macroplastic visually identified was discriminated by the Supervised Classification. Once these factors have been considered, new UAV surveys experiments can be performed and once validated monitoring activities can be carried out without field surveillance reducing costs in time and resources. Finally, further studies should be developed to investigate variability results under different conditions.

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