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Micro plastics mapping in the agricultural sector of Cyprus

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Abstract

The impact of Microplastic Pollution (MPs) on human health, the environment, economy, and society has been previously investigated. However, there is a lack of comprehensive understanding regarding specific areas that require urgent measures to address marine pollution. The accumulation of MPs in Mediterranean coastal environments is particularly noteworthy. This is attributed to the region's economic reliance on tourism and the decline of popular tourist destinations caused by the presence of coastal and marine waste. The objective of the present research was to conduct a strategic analysis and mapping of MPs from soil samples taken from rural areas of Cyprus. Within the framework of the present research, a general picture of the status of MP pollution in areas covering significant percentages in the domestic supply of fruits and vegetables was obtained. The survey indicated the presence of more than 70% of MPs in crops at a concentration of up to 1.5 %. As a result of this research, the need to highlight the importance of the rational use of plastics and proper management to mitigate pollution is a primary concern. The rational separation of materials for recycling, information, reuse of materials, processing, and an increase in the number of recycling bins in public places are considered urgent. Cooperation between the state, institutions and industry must be based on the protection of people and the environment.

Keywords: Microplastics, agriculture, Mediterranean, monitoring, soil, extraction

1. Introduction

The understanding of microplastics (MPs) effects have significantly evolved since they were first identified as microscopic particles around 20 μm in diameter by Thompson et al. (2004). Nowadays, MPs are defined as synthetic organic polymers (Zhang et al., 2021), which have oil and gas as their source (Thompson et al., 2004) with a maximum size of at 5 mm (Chatziparaskeva et al., 2022b; Hartmann et al., 2019; Liu et al., 2021). Those particles have been detected in various environments, including oceans, rivers and agricultural areas (H. Yang et al., 2021). From 2010 onwards, the European Union (EU) has experienced a significant increase in overall plastics production, peaking at nearly 700 million metric tons (Statista, 2024a). MPs entering the agricultural sector through various pathways, such as irrigation water, application of plastic mulch in farming practices and also the use of plastic-based agricultural products. Mapping of MPs is essential for understanding their distribution and impacts in the agricultural sector assessing their presence and potential risks to crops, soil health, and food safety (Yu et al., 2021).

1.1. Microplastic statistics around the world

MPs have been found in supposedly untouched environments such as Arctic Sea ice (Kanhai et al., 2020) isolated mountain ranges (Padha et al., 2022), and deep ocean trenches (Peng et al., 2018). Only 5% of the value of plastic packaging remains in the economy - the rest is discarded, demonstrating the need for a more holistic approach (European Commission, 2018). According to the United Nations (UN) (2017), there are at least 51 trillion MP particles in the seas. The MPs found in the sea often become food for fish, which then end up on the consumer's table as they follow the food chain (McIlwraith et al., 2021). MPs have been found in food and beverages such as beer, honey and drinking water. Despite comprising only 1% of the global water, the Mediterranean holds 7% of global MPs, one of the highest levels of plastic pollution in the world generating about 730 tons/day plastic waste (Chatziparaskeva et al., 2022b). The largest beaching rate (net number of particles deposited daily per kilometer of beach) in the Mediterranean, was recorded in Egypt and Algeria with 43–47 kg/km/day deposited from the coast (Baudena et al., 2022).

According to the World Wildlife Fund (WWF) (2018), the Mediterranean Sea has experienced an unprecedented surge in MP concentration, reaching a record level of 1.25 million fragments per km^2, nearly four times greater than the density found in the "plastic island" discovered in the North Pacific Ocean. Concerning agricultural soils, the average number of plastics found was 664 items per kg of soil, with most being found in polytunnel (average 25069 items per kilo) and greenhouses (average 2986 items per kilo) at the 0-20 cm soil layer (Li et al., 2023; Wang et al., 2021). MPs volumes are projected to drastically increase as the amount of mismanaged plastic is expected to increase from 0–99 million tons per year in 2015 to 155–265 million tons per year by 2060 (Lebreton and Andrady, 2019).

1.2. MPs Pollution

MPs distribution in the environment pose significant challenges to all three pillars of sustainability (environment, economy, society) (Figure 1) by contaminating soil and water is entering the food chain threating biodiversity and human health (Yu et al., 2021). The repercussions of surge in MPs extend beyond environmental concerns, in-filtrating the human food chain and posing potential threats to human health (Ebrahimi et al., 2022; Yu et al., 2021). MPs not only contain additives but also transfer other contaminants to humans through consumption, including toxic organic chemicals known as Persistent Organic Pollutants (POPs) such as polychlorinated biphenyls (PCBs) and dioxins (Alfaro-Núñez et al., 2021; Chatziparaskeva et al., 2022b). The presence of MPs in human organisms from EU countries (e.g., Italy, Austria, etc.), with Polypropylene (PP) and Polyethylene terephthalate (PET) constitute 80% of human stool (Ebrahimi et al., 2022). At the same time the detection of metals, such as aluminum, arsenic, lead, and mercury are also associated with these polymers, with significant implications for human health, including oxidative stress, nutrient deficiency, congenital disabilities, inflammation, translocation, and cancer (Barboza et al., 2020; Ebrahimi et al., 2022). MPs found in the oceans often serve as unintended food for marine organisms, entering the marine food web. Fish consume these particles, creating a pathway for MPs to reach consumers through seafood consumption. While the precise health effects of MPs entering the food chain are not yet fully understood, it is well-established that plastics often contain additives like stabilizers, flame retardants, and other potentially toxic chemicals (Ebrahimi et al., 2022). The potential harm to both animals and humans raises concerns about the long-term consequences of MP exposure through dietary intake.

The proliferation of marine litter, largely composed of plastics, adversely affects sectors such as fisheries and communities dependent on marine resources. The economic impact is stark, with only 5% of the value of plastic packaging remaining in the economy, while the majority is discarded. This scenario emphasizes the urgency for a more comprehensive and sustainable approach to address the life cycle of plastic products (Chatziparaskeva et al., 2022a). Considering these multifaceted impacts, there is an imperative need for comprehensive research to elucidate the exact consequences of MPs on both ecosystems and human health. This knowledge is fundamental for developing effective strategies to mitigate the proliferation of MPs and safeguard environmental and human well-being (European Commission, 2018; News European Parliament, 2021; Official Journal of the European Union, 2019).

[Figure 1. Sustainability Chart]

While plastic pollution in oceans has garnered significant attention, the presence of MPs in soil has been a relatively understudied but critical concern. Research indicates that plastic accumulation on land can be 4 to 23 times higher than that in the oceans (de Souza Machado et al., 2018; Horton et al., 2017), underscoring the substantial impact of plastic waste on terrestrial ecosystems. Despite these findings, human understanding of soil pollution by MPs is still limited. The global surge in plastic waste is a growing environmental challenge, with approximately 79% (González-Fernández et al., 2021) of this waste accumulating in landfills and other terrestrial compartments, including agroecosystems (Hossain et al., 2023; Igalavithana et al., 2022; Loizia et al., 2021a; Nizzetto et al., 2016). This emphasizes the pressing need to investigate and comprehend the extent of MPs pollution in soil, as it plays a crucial role in agricultural and eco-logical systems (Okoffo et al., 2021).

1.3. EU legislations and initiatives on Plastic Waste

The European Commission's (EC) commitment in combating MPs pollution is outlined in both European Green Deal (EGD) and the Circular Economy Action Plan (CEAP). Under the Zero Pollution Action Plan, EC aims to reduce 30% of MP pollution by 2030. For achieving its goal, European Parliament has initiated several strategic initiatives, primarily focusing in addressing plastic pollution within the community (Chatziparaskeva et al., 2022b; European Commission, 2019, 2015).

Regarding the legislative framework of waste management, the EU has set the Waste Framework Directive (WFD) 2008/98/EC, through which it encouraged Member States to create separate waste sorting for glass, plastic, metal, and paper by 2015. It also requires the preparation for reuse and recycling of waste materials (paper, metal, plastic and glass) from households and possibly from other sources, at least 50 % by weight in total, by 2020 (European Commission, 2008). The new directive WFD (EU 2018/851) approved in May 2018, established a minimum target requiring that by 2035, at least 65% of municipal waste weight must be prepared for re-use and recycling. The revised WFD was amended in 2018 to strengthen waste prevention by implementing the waste hierarchy, setting new targets for waste and recycling. In particular, the legislative framework Law 185/2011 (Directive 2008/98/EC) sets a new target for a reduction of at least 50%, in terms of total weight, at least in paper, metal, plastic and glass waste by 2020 (European Commission, 2008).

As a baseline and common point of reference regarding sustainability endeavors, in 2015, the UN introduced the 17 Sustainable Development Goals (SDGs), accompanied by a set of targets and indicators (United Nations, 2015). Combating MP pollution is linked with many SDGs which include but are not limited to SDG 12 which focuses on ensuring sustainable consumption and production patterns. Specifically, target 12.5 advocates for the reduction of plastic pollution through measures such as prevention, reduction, reuse, and recycling of plastic items. To assess the progress achieving this target, the national rate and quantity of recycling are taken into consideration (United Nations, 2015; Walker, 2021). At the same time, SDG 14 'Life Below Water' and SDG 15 'Life on Land' illustrate the imperative need of protection and rehabilitation of both aquatic and land ecosystem (Walker, 2021). Runoff from water sources can transport MPs to soil and water bodies potentially affecting land-dwelling, aquatic organisms and ecosystems (Chatziparaskeva et al., 2022b). In addition, SDG 3 targets on ‘Good Health and Well-being’ addressing to ensure healthy lives and promoting well-being for all ages while SDG 11 strives for sustainable cities and communities (United Nations, 2015).

Furthermore, in the realms of circular economy and the transformation of linear production lines to circular ones, the EC adopted the CEAP in March 2020, constructing one of the main pillars of the EGD and EU’s new agenda for sustainable growth (European Commission, 2020a). Transitioning to a circular economy has the potential to reduce the stain on natural resources creating sustainable growth and new career opportunities. This is an essential step in the effort to achieve the EU's target by 2050 for climate neutrality and to halt biodiversity loss (Colasante et al., 2022). The CEAP introduces initiatives along the entire life cycle of products, focusing on products designed, promoting circular economy processes, encouraging sustainable consumption and finally aiming to ensure that waste is prevented maximizing the retention of resources within the EU economy (European Commission, 2020a). Highlighted in the EGD, the EU Biodiversity Strategy 2030 (Montanarella and Panagos, 2021), and the Farm to Fork strategy (European Commission, 2020b), there is a coordinated push to accelerate the growth of a circular economy culture across all sectors of the economy (Modibbo et al., 2022).

Moving on to October 2023, the EC set Regulation (EU) 2023/2055 which contributes to the restriction of MPs in everyday products, thus protecting the environment and human (European Commission, 2023). The main measure adopted by the Regulation is the ban of primary MPs sale and products that use them like glitter, waxes, facial scrubs, certain fertilizers, plant protection products and seeds treated with them, biocides etc.

In the accord of previously mentioned legislations, strategies and action plans, the Department of Environment of Cyprus developed relevant legislation Law 32(I)/2002 (Directive 94/62/EC) according to which the following targets were to be achieved by 31.12.12, targets which were not achieved (by weight percentage) (Republic of Cyprus, n.d.):

[Table 1. Cyprus Waste Management Targets and Results for 2012 (Republic of Cyprus, n.d.)]

1.3. Agriculture in Cyprus and MPs

Agriculture has always been an important production sector of the Cypriot economy. Upon the establishment of the Republic of Cyprus in 1960, it constituted approximately 20% of the Gross Domestic Product (GDP) and employed around 36% of the working population (Cyprus Profile, 2022). Over time, various changes in both the economic environment (such as the Turkish invasion, EU accession and trade liberalization) and social structures, have led to a diminishing significance of the rural economy. For instance, after the Turkish invasion in 1974, the country lost most of the fertile land, mostly cultivated by cereal crops, citrus, olive trees and all the tobacco. Since then, the Cypriot economy is characterized by the growth of the tertiary sector (tourism and service sector) and the contraction of the primary and secondary sectors of the economy (Ministry of Agriculture rural development and the environment, 2017). One of the main characteristics of Cypriot agriculture is that most of the primary production comes from small family businesses, working under strict EU standards, and therefore supporting their competitiveness is of paramount importance (Ministry of Agriculture rural development and the environment, 2017). In 2000 the primary sector accounted for 3.8% of the total GDP of the Cypriot economy, while in in 2022, the value added to agricultural production reached nearly 412 million USD, accounting for 1.65% of the GDP (Statista, 2022a) (Figure 2) and employed about 10 thousand people (Cystat Statistical Service, 2020) (Figure 3).

[Figure 2. Distribution of gross domestic product (GDP) of Cyprus across economic sectors from 2012 to 2022 (Statista, 2022b)]

[Figure 3. Distribution of employment in Cyprus by economic sector from 2011 to 2021 (Statista, 2024b)]

The decline in the gross value of agricultural output in real terms is close to 10% and can partly be attributed to the significant reduction in the area under cultivation. The rich soil, combined with the semi-arid Mediterranean climate of Cyprus offer favorable conditions of early harvesting of high-quality products (i.e. tomatoes, potatoes etc.), which ensures access to niche markets (Economou et al., 2023). Figure 4 shows the main agriculture products of Cyprus, their total production, and the average yield for the year 2022.

[Figure 4. Crop production overview in Cyprus for the year 2022- Data from FAO,(2022)]

Regarding MPs in agriculture, the use of polymers in the agricultural sector is particularly extensive, as they are used in many agricultural operations (Campanale et al., 2024; Samuelson et al., 2022) Plastic parts, tools as well as substrates are essential agricultural equipment, while their exposure to weather conditions (i.e. sun, rain, wind etc.) is capable of causing their degradation into smaller pieces. As a results, these smaller fragments (MPs) are either transported by waterborne systems or air to downstream areas or disposed in the soil (Piehl et al., 2018).

The widely used plastic coating films is one of the important sources of MPs in agricultural soils (Huang et al., 2020; Wang et al., 2021), as it is directly applied on soil in large quantities. For example, agricultural soils in the coastal plain of Hangzhou Bay in eastern

China showcased higher average MP abundance on the surface of coated soils than uncoated soils with 571 and 263 particles per kg, respectively (Zhou et al., 2018).

The use of plastic membranes as a ground cover sheet, is widely used in crops to inhibit weed growth, retain heat in the root system, limit water evaporation, stabilize the soil, protect against insects and severe weather conditions (Zhang et al., 2021). Depending on their purpose of use, ground cover leaves have different characteristics such as thickness, color, type of material, density resulting in different decomposition mode and different lifetime (Campanale et al., 2024). Park and Kim (2022) showed that the plastic particle sizes were smaller in fields that were ploughed and around greenhouses, as the membranes had been worn for a long time and that the particle size distribution depends on the type of plastic, the degree and duration of environmental exposure (Kim et al., 2022). The concentration of MPs is higher in the top soil (0-20 cm) the most MPs found in agricultural soils are smaller than 0.5 mm consisting of films, PE and PP (Li et al., 2023). In Cyprus, plastic membranes are used for a significant number of crops such as watermelons, tomatoes, bananas, cucumbers etc.

1.3.1. Banana Cultivation

The cultivated area with bananas amounts to about 235 hectares with the production being located in the western coastal area of Paphos. In 2018 the production of bananas amounted to about 5,800 tons, worth 6.5 million EUR (2.2% of the total value of the plant production). In addition to its important role in the total value of plant production, its role in the local biodiversity and the tropical character of the region is noticeable (FAO, 2022).

Covering individual banana brunches with plastic bags is a common crop management practice, which can cause transport and deposition of plastics in the soil and the environment (Yang et al., 2022). Covering banana brunches with suitable plastic bags is intended to keep the fruit clean from dust and bird droppings while protecting them from weather conditions (i.e. hail) and damage caused by pest. These protective coverings can also help accelerate the ripening of the fruits due to the increase in temperature and improve fruit quality (Ahmad Fizar et al., 2022; Kristiyani et al., 2023).

1.3.2. Low Tunnel Greenhouse

Low tunnels greenhouses consist of small arched structure (0,80 – 1 m height) covered with plastic film, offering protection to crop during the early stages, against pest and weather conditions. The primary purpose of the low tunnels is to assist the growing cycle of crop, enabling production during periods of the year when it would otherwise be impractical without this technique (López-Martínez et al., 2021). These techniques in Cyprus are mainly employed to advance harvesting period of watermelons, protect the fruit and enhance the color of strawberries and protect sensitive vegetable crops from bruises such as courgette and eggplants.

1.3.3. Citrus

Citrus is the second most important crop in Cyprus, following potatoes, primarily oriented towards export. During the 2000/2001 season, the export volume amounted 205 thousand tones, with oranges accounting for 50% (Fruitrop, 2001). In subsequent years, citrus cultivation has experienced a significant decline attributed to rising production costs and trade limitations. By 2020, the export value had decreased substantially to 41.5 million, positioning Cyprus's citrus industry at 30th place globally (OEC, 2022). The use of plastic in citrus cultivation is very limited, as there is almost no use of mulching films or other similar products. Nonetheless, the use of yellow sticky traps in citrus cultivation, primarily for insect control and protection against the Mediterranean fruit fly, contributes to the pollution of agricultural soil. Additionally, the absence of proper implementation of good agricultural practices results in the plastic pollution of orchards from packaging material of fertilizer and pesticides (Rodríguez-Espinosa et al., 2023).

The aim of this research was to comprehensively investigate MP contamination in crops and identify its sources and dispersion in soil. Soil samples were meticulously gathered from various crop varieties across three provinces in Cyprus island, and MPs were isolated using a saturated sodium chloride solution. Through laboratory analyses and mapping procedures, the research sought to establish correlations between soil type, crop diversity, and the presence and proportion of MPs.

2. Methodology

The central aspect of the methodology involved the collection of soil samples from 34 locations across cultivated plots spanning three provinces of Cyprus (Famagusta, Limassol and Paphos). The sites were selected based on data provided by the Cyprus Statistical Service, about the main crops cultivated in Cyprus and their corresponding locations. Particularly the following facts were taken into consideration: i) extensive use of soil cover membranes in the crops (mainly Cucurbitaceae) of Famagusta district, ii) use of plastic bags to cover banana clones in the western areas of Paphos province, and iii) Frequent use of insecticides and traps on citrus crops in Limassol district. These sites encompassed various crops, including bananas, citrus fruits, cereals, vegetables, and greenhouse fruits. Sampling took place from May 2023 to September 2023, utilizing the volume reduction method – reducing the amount of material in both volume and weight. This method, introduced by the research group of Hidalgo-Ruz et al. (2012), is suitable for managing large sample volumes during processing. Sampling proceeded through several stages such as initial visits to sampling sites involved gathering information on site characteristics and land use. Specifically, records were compiled regarding: (i) Crop type, (ii) Soil material type and (iii) Visual assessments of topography, morphology, and hydrology. To ascertain the cultivation type, soil classification, hydrological conditions, and land usage, we conducted on-site observations and obtained digital data/maps from the Cyprus Geological Survey Department (CGSD) and Copernicus Land Monitoring Services.

2.1. Study Area

As previously indicated, the districts of Famagusta, Limassol, and Paphos were designated as study sites. Specifically, the Peyia area within the Paphos district was chosen, notable for hosting the largest banana cultivation area in Cyprus (FAO, 2022). These plantations extensively utilize disposable plastic bags for fruit protection, observed to fragment easily into smaller pieces and accumulate on the soil. In the Fassouri area of the Limassol district, citrus fruits were selected for their substantial pesticide plastic packaging originated from agrochemical inputs and flytrap usage (FAO, 2022). Additionally, the area's proximity to a busy road network results in a significant presence of waste due to frequent illegal dumbing and visitor traffic. The Famagusta district, where it has the majority of samples collected, was selected for its diverse crop types, including leafy vegetables and watermelons (FAO, 2022). These crops require various protective measures across their biological cycle, such as greenhouses, water irrigation systems, and soil amendments (Campanale et al., 2024; Huang et al., 2020; Piehl et al., 2018; Wang et al., 2021).

The study areas, along with the sampling locations, geological map, and land use map, are depicted in Figure 5. Mapping was performed using the ArcMap Pro software, utilizing geographic coordinates gathered during sampling, in conjunction with maps sourced from the CGSD (n.d.) and Copernicus Land Monitoring Services (2018). The Corine Land Cover map corroborates that the under-study plots are utilized for cultivation purposes. According to the geological map 250k from CGSD, these parcels mainly lie within areas characterized by sedimentary soil, primarily owing to alluvial and fluvial deposits from the Holocene era.

[Figure 5. Mapping of Soil Samples Location (red dots), Corine Land Cover Map of 2018 and Geology Map 1994 (CGSD, n.d.; Copernicus Land Monitoring Services, 2018)]

2.2.Soil Sampling

Surface material sampling (at a depth of 0-0.10 meters, or topsoil) (Frouz, 2021) was conducted at a distance of over 20 meters from roads to minimize the risk of plastic contamination stemming from automotive traffic- the samples should primarily focus on assessing the presence of plastics in crops, including airborne and waterborne sources. At each study site, 3-4 subsamples weighing 3-5 kilograms each were extracted using appropriate steel spades, referencing methodologies outlined by several researchers (Claessens et al., 2013; Hidalgo-Ruz et al., 2012; Löder and Gerdts, 2015; Zhang and Liu, 2018; Zhang et al., 2020).

Sampling points at each site were limited to a maximum of five, distributed within a 3 x 3-meter grid as illustrated in Figure 6. The cumulative subsamples (a, b, c, d, and e) comprised the sample collected from each tested point. The subsamples were carefully deposited into airtight plastic bags, previously rinsed with distilled water. These bags were labeled with pertinent sample information including geographic coordinates, sampler identity, date, province, sample number, and land use, before being transported to the laboratory for analysis. After each sampling, soil samples were promptly extracted from the sampling tool's surface and securely packed. Subsequently, the tool underwent thorough cleaning and rinsing with distilled water in preparation for subsequent use.

[Figure 6. Schematic representation of soil material sampling per location]

Following sample collection, samples were transported to the laboratory where they were organized, documented in databases containing essential information such as geographical coordinates, crop type, and numbering. Subsequently, the samples were carefully placed and sealed in disposable aluminum trays, then preserved at -20±2 ºC in a suitable refrigerator until experimental controls were conducted, as recommended by Pagter et al. (2018).

Upon completion of the sampling phase, the samples underwent drying procedures maintaining a constant temperature of 70±5 ºC for 24 hours. After this initial drying period, the samples were removed from the furnace, weighed, and then placed back into the furnace for an additional two hours. The process was repeated until the mass remained consistent. This methodology adheres to the standards outlined in EN 933: Part 1 (CEN, 2012), with the selected temperature aligning with methodologies proposed by Phuong et al. (2018) and Zhang et al. (2020), ensuring the prevention of polymer melting in the samples.

Each sample underwent quadruplication to facilitate separation and reduce portion sizes. In our procedure, during the quadruplication process, the sample slated for testing was delicately deposited onto a flat surface to form a cone (CEN, 1999). Subsequently, using a spatula, the sample was stirred, flattened, and divided into four quadrants. Two quadrants were then removed, and the process was repeated until the desired portion sizes were obtained. For laboratory testing, each sample was further divided to yield two equal portions weighing 100g each (one for sample and the other for anti-sample for MPs extraction), while the remaining portion was designated for particle size analysis - soil classification. The entire process can be depicted in Figure 7.

[Figure 7. Methodology Analysis Following Sample Transfer to the Laboratory]

2.3.Particle size analysis

Particle size distribution stands as one of the fundamental soil classification procedures globally, providing essential insights into soil properties (Sowiński et al., 2023; Wang et al., 2022). To conduct particle size analyses and classify the 34 samples in line with British Standard BS 1377: Part 2 of 2022 (BSI, 2022) and ISO 17892-4 (ISO, 2022), various techniques were employed. Table 1 presents the general soil classification based on grain size, as outlined in the second annex of British Standard BS1377 (BSI, 2022), which are widely acknowledged within the EU community.

[Table 2. Soil Classification According to BS 1377: Part 2 of 2022 (BSI, 2022)]

To conduct particle size analyses, the 34 portions obtained from sample quadruplication were processed using a 30 mm diameter impact sieve series specified in Table 2. Following BS1377 - Part 2 (BSI, 2022) guidelines, soil portions were oven-dried at 110±5°C until mass stabilization, then washed through a 0.063 mm sieve and dried again for 24 hours. The remaining soil portion was reweighted, and sieved for another 10 minutes with the series of the sieves as shown in Table 3. The weight of material retained in each sieve was measured and calculated relative to the original sample weight. Parameters such as D10, Cu, and Cc were determined from the semi-logarithmic curve. Samples with over 70% mass loss after washing through a 0.075 mm sieve underwent particle size analysis using a 151H diluter according to ASTM D7928-17 (ANSI, 2017).

[Table 3. Series of Impact sieves with a diameter of 30 mm used for samples Particle Size Distribution]

2.4.Extraction of MPs from Samples

To extract MPs from the 34 samples, we utilized a saturated sodium chloride (NaCl) solution with a concentration of 1.2 g/ml. The use of NaCl solution concentration is preferred by numerous researchers for its cost-effectiveness and environmentally friendly properties although not optimal for high-density polymers (Claessens et al., 2013; Mai et al., 2018; Thompson et al., 2004; Zhang et al., 2020, 2018).

A fixed mass sample of 100 g (grain size < 5 mm) was placed in a glass volumetric cylinder, then 500 ml of NaCl solution of 1.2 g/ml concentration was added, the volumetric cylinder was sealed with a suitable stopper, and manual stirring was performed for 30 seconds (stirring is performed with 180° rotations of the volumetric cylinder). The stopper was then removed and wash with a few ml of distill water (about 5 ml) over the cylinder to remove any soil particles or/and MPs. The sample was left to stand for 6 hours in the case of sand and 24 hours in the case of fine-grained material (silt and clay) at a laboratory temperature of 25 °C. At the end of 24 hours, the floating elements were removed by overflowing and placed on 2-3 μm filter paper to dry. The polymers identified per sample were placed in clear, airtight plastic bags of a specific mass and then weighed on a calibrated balance of 3 decimal places.

3. Results and Discussion

The research indicated the presence of MPs in more than 70% of the crops sampled. Soil samples were specifically collected from the topsoil due to the greater influence of MPs. These findings agree with the research by Li et al. (2023), who examined the vertical distribution of MPs across different land uses (forest, grassland, crops) and similarly concluded that MPs were most concentrated in the topsoil.

In the Paphos district, MPs were found in all samples collected from banana cultivation plots, with concentrations ranging from 0.5-0.62%. These MPs were primarily identified as remnants of plastic bags used to cover the fruit, which had deteriorated over time. In the Limassol district, MPs were detected in 66.7% of samples taken from citrus fruit areas, with concentrations ranging from 0.5-1.5‰, mainly originating from fragmented yellow flytraps. Lastly, in the Famagusta district, MPs were identified in 63.2% of samples, with concentrations of 0.7-0.92‰, primarily attributed to coating membranes. The percentage findings of MPs from samples gathering from Famagusta, Limassol and Paphos districts are illustrated in Figure 8 and photos are illustrated in Figure 9.

[Figure 8. Percentage results of MPs from samples collected from Famagusta, Limassol and Paphos district]

[Figure 9. Percentage results of MPs from samples collected from the three districts, photos of the extracted MPs, as well as the crops in which they are utilized]

The practice of bagging bananas is a common method of cultivation, as it keeps the fruits clean from dust and bird droppings while protecting them from weather conditions such as hail (Chaiwong et al., 2021; Rubel et al., 2020). This method can accelerate the ripening of the fruit due to the increase in temperature. In the samples collected from banana cultivation sites in Paphos province, the MPs detected were mainly composed of blue plastic bags (waste) used for this cover. The covering of banana fruit clones should be done with appropriate, biodegradable or reusable plastic bags which can be collected and properly managed by the farmer so that they do not decompose and remain in the soil. The deposition of these bags on the ground can have a terrible impact on biodiversity, the food chain, but also on society and tourism.

Widely used plastic coating films are also an important source of MPs in agricultural soils (Fan et al., 2023; Huang et al., 2020) and the residual film can be further broken down into MPs. Soil cover films which were detected in a significant number of samples in Famagusta province are mainly used to inhibit weed growth, reduce water evaporation, maintain soil temperature, stabilize soil and protect plants from insects. The main issues arising from the use of plastic sheets in crops depend on their shelf life and their management after their use. The research by Li et al. (2023), concluded that in agricultural soils most MPs are less than 0.5 mm consisting of plastic films, PE and PP. These plastics, although considered biodegradable, have a long lifespan (manufacturing specifications exceed 3 years while much longer lifespan is targeted).

Farmers avoid reusing them and their inappropriate management results in them being broken down into smaller pieces and incorporated into the soil material. The phenomenon is globally widespread, for example, agricultural soils in the coastal plain of Hangzhou Bay in eastern China showed higher average MP abundance on the surface of coated soils compared to uncoated soils with 571 and 263 particles per kg, respectively (Zhou et al., 2018). A study by Yang et al. (2021) indicated the effects that continuous and long-term application of pig manure from piggeries can have on crops; results showed that the soil with continuous application of manure had 43.8 ± 16.2 particles/kg while the field with no application had 16.4 ± 2.7 particles/kg. The estimated rate of plastic accumulation in the soil is estimated to be about 3.50 ± 1.71 particles/ha/yr.

The distribution of MPs in soil is influenced by various factors, including soil granule size, polymer particle size, plastic type, and duration of environmental exposure (Economou et al., 2023). In agricultural fine-grained soils, most plastics are classified as micro and nano plastics, while in coarse-grained and uncultivated soils, larger plastics are found. This conclusion is confirmed by the research of Li et al. (2023), and Park and Kim (2022). They concluded that the sizes of plastic particles were smaller in fields that were ploughed and around greenhouses, as the membranes had been worn for a long time, while relatively large sizes of MPs were found in uncultivated soils.

Regarding the extraction method of MPs with saturate NaCl solution from the samples its effectiveness depends on the type of polymers, the density of the particles, the time they remain in nature. It is suitable for the extraction of most plastics (low density plastics), while for high density plastics the results depend on the concentration and the state of the plastics (in cases of degradation it is easier to floated and recover them) (Nabi et al., 2022). Monteiro and Costa (2022), examined the efficiency of NaCl, $ZnCl_2$ and NaI for extracting MPs in complex solid, water and biota samples. The results were similar for the higher for the two salt solutions with NaI showing a mean rate of 98% and $ZnCl_2$ about 91%, compared to NaCl that scored 81% efficiency rate. As a recommendation, the combination of NaCl with NaI and $ZnCl_2$ is a suitable alterative for a cheaper solution with high recovery rates (93 %). A novel separation method using canola oil and unsaturated NaCl solution for the extraction of MPs was tested in five typical Japanese agricultural soils (Han et al., 2019). The result showed high recovery rates for LDPE (95.2–98.3%) and PP (95.2–98.7%), with less sensitivity to soil type, texture, and physicochemical properties. Lastly, a mixture of NaCl and NaI as a floatation solution was proposed, with significant improvement in recovery rates and to achieve a density greater than the most common plastic materials (Kononov et al., 2022).

3.3.Recommendations

The prevalence of MPs in agricultural soils is steadily increasing (Fan et al., 2023), necessitating a strategic and comprehensive approach to its management. Addressing this challenge requires a holistic and collaborative effort, integrating sustainable practices at every stage of the agricultural supply chain. This research aims to conduct extensive data collection to determinate the types, sources and distribution of MPs in rural areas. Through this understanding, more targeted actions can be taken for a more effective response (Figure 10).

[Figure 10. Strategic planning proposals for the reduction of MPs in agriculture soil]

The most immediate measure involves educating farmers and the public about the impact of MPs on soil health and food safety (Eliades et al., 2022). The aim is to raise awareness among farmers about the importance of their daily practices and how they affect their crops in the long term, encouraging the adoption of sustainable alternatives (Colasante and D'Adamo, 2021; Pazienza and De Lucia, 2020).

The use of biodegradable ground cover materials, made from materials such as cellulose, linear low-density polyethylene (LLDPE) or other organic compounds, is a practice that is already in use, but farmers often lack knowledge about their proper use Clear standards and proper labeling, established through cooperation with authorities and certification bodies, are necessary (Loizia et al., 2021b).

At the same time, the Agricultural Research Institute can contribute to field research that will examine the decomposition time of different types of biodegradable plastic covers. Promoting natural ground cover options and setting maximum acceptable MP limits in soil, alongside incentives for sustainable practices, can encourage better plastic use (Pazienza & De Lucia, 2020).

Effective waste management to reduce plastic pollution at source is another important measure (Zorpas et al., 2021). Encouraging recycling initiatives for agricultural plastics and developing programs for the responsible disposal reusing greenhouse sheets, and implementing in-field recycling are key measures**.** Note that most of the farmers practice recycling empty pesticide bottles in special bags, which the companies supplying them are also responsible for collecting them from the farm (Stylianou et al., 2023). The collection of recyclable agricultural materials can take place either on the farm or through designated collection centers (De Lucia and Pazienza, 2019; Pazienza and De Lucia, 2020).

4. Conclusion

The study aimed at providing valuable insights into the extent of plastic pollution in agricultural soils in Cyprus utilizing the MPs extraction method using NaCl. The methodology employed in this study include the collection of soil samples from various agricultural crops, in three provinces of Cyprus: Famagusta, Limassol and Paphos. Cultivation areas and types were chosen based on their importance for Cyprus and the agricultural practices employed, including banana plantations, citrus fruit orchards, and vegetable fields. The results reveal a severe presence of MPs in agricultural soils across the three provinces with Paphos exhibiting complete contamination. Mapping of samples is an important tool to correlate the results with a variety of factors such as morphology, hydrology, geology (soil type) and land use. By visually representing the spatial distribution of samples, maps can provide a comprehensive understanding of the study area, helping to identify trends, hotspots and correlation between those factors. This can facilitate the interpretation of the results, promoting cooperation and communication between stakeholders by conveying complex information in an understandable way. Thus, making it a powerful communication tool for researchers to collaborate and share the existing knowledge with stakeholders in all levels, including policymakers, agricultural practitioners, environmental organizations, and the public.

Agriculture pollution caused by MPs is not conducive to sustainability posing long-term risk to both environment and human health. The issue of MPs in undermines the significance of sustainable farming and the capacity of the sector to preserve ecosystem health and mitigate climate change. Agriculture must guarantee the production of safe, nutritious food while safe-guarding ecosystem. Research outcome in this field can provide an understanding into the drivers and pathways through which MPs enter agricultural soils. This information is invaluable for the strategic planning, required to reduce plastic pollution at international level in order to preserve the primary sector and fostering sustainable development. This includes measures to reduce plastic pollution at its source, by implementing policies and directives that establish minimum waste management standards for plastic products, enhance waste management infrastructure, and advocate for alternative cultivation practices, while encouraging the use of biodegradable plastics.

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TABLES

Table 1. Cyprus Waste Management Targets and Results for 2012 (Republic of Cyprus, n.d.)

a/a	Target (2012)	Results (2012)
Recovery / incineration, in waste incineration plants with energy recovery	60%	55.3%,
Recycling	55 - 80%	55.7%
Glass	60%	32.4%
Paper and cardboard	60%	88.9%
Metals	50%	98.8%
Plastics	23%	44.8%
Wood	15%	6.2%

Table 2. Soil Classification According to BS 1377: Part 2 of 2022 (BSI, 2022)

Soil Type		Particle Size (mm)
Gravel	Boulder	>256.00
	Cobble	256.00-64.00
	Pebble	64.00-4.00
	Granule	4.00-2.00
Sand	Very Coarse	2.00-1.00
	Coarse	1.00-0.50
	Medium	0.500-0.250
	Fine	0.250-0.125
	Very Fine	0.125-0.063
Silt	Coarse	0.0625-0.031
	Medium	0.031-0.0156
	Fine	0.0078-0.0156
	Very Fine	0.0039-0.0078
Clay		<0.0039

Table 3. Series of Impact sieves with a diameter of 30mm used for samples Particle Size Distribution

a/a	**Sieves' Square Mesh Size (mm)**
1	8
2	6.3
3	5
4	4
5	2
6	1
7	0.600
8	0.500
9	0.300
10	0.250
11	0.125
12	0.063

FIGURES

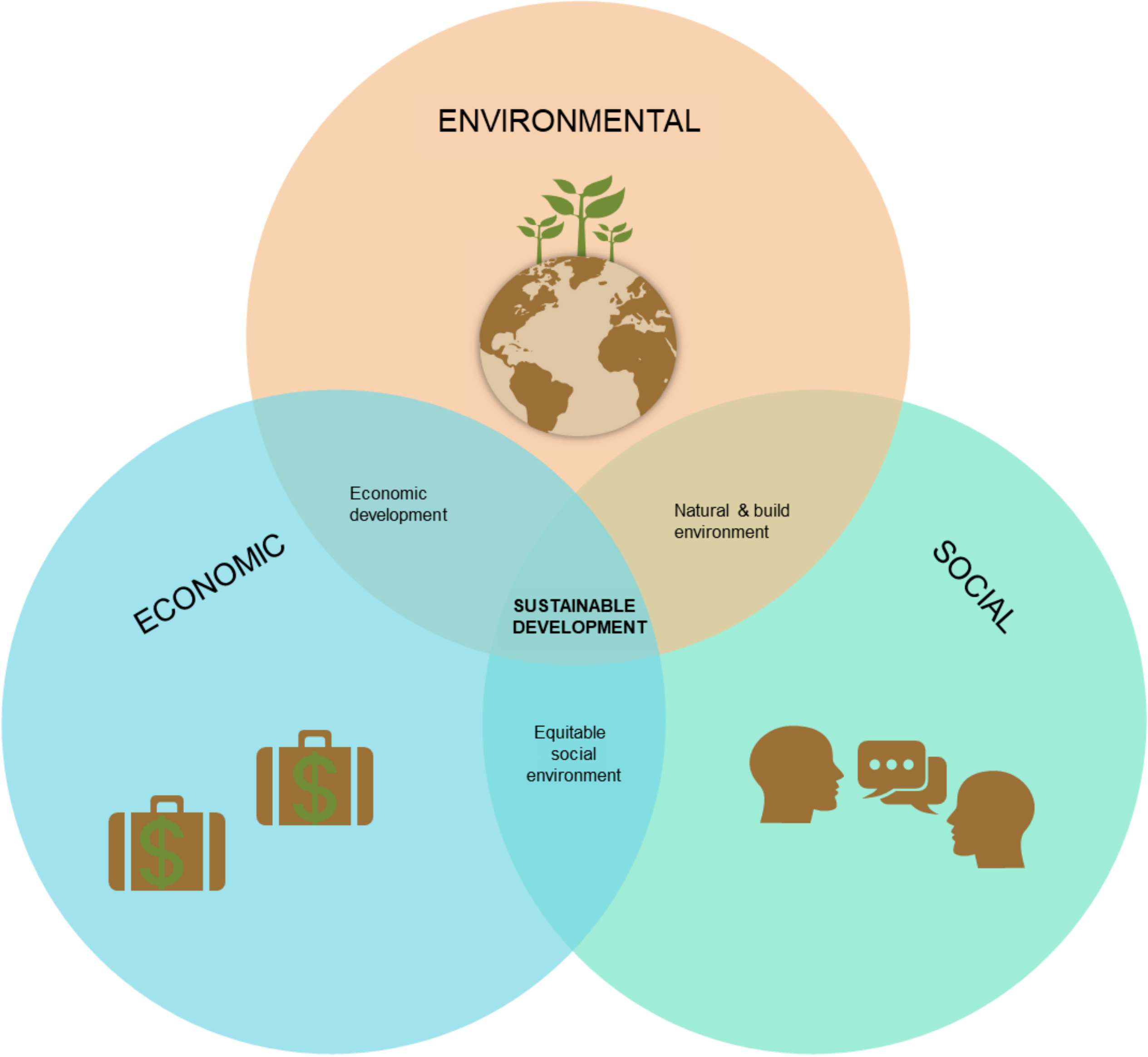

Figure 1. Sustainability Chart

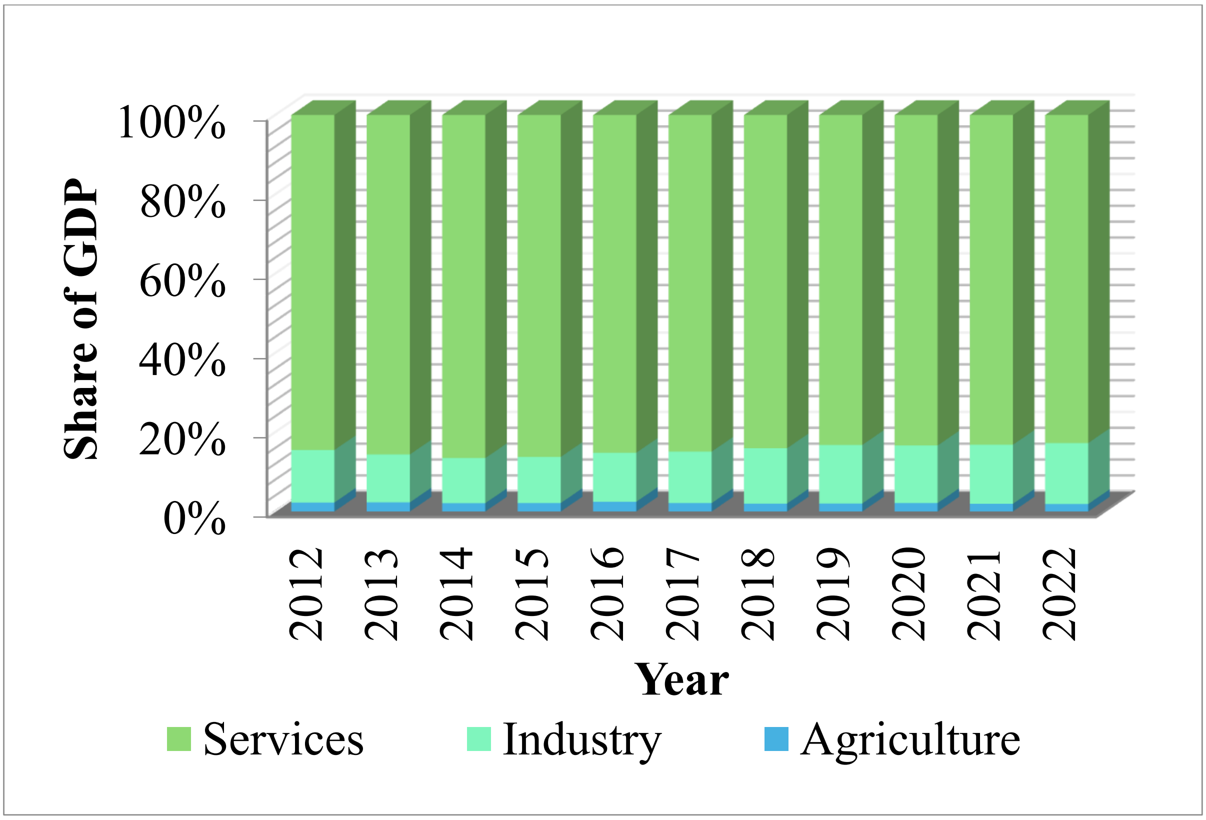

Figure 2. Distribution of gross domestic product (GDP) of Cyprus across economic sectors from 2012 to 2022 (data from Statista, 2022b)

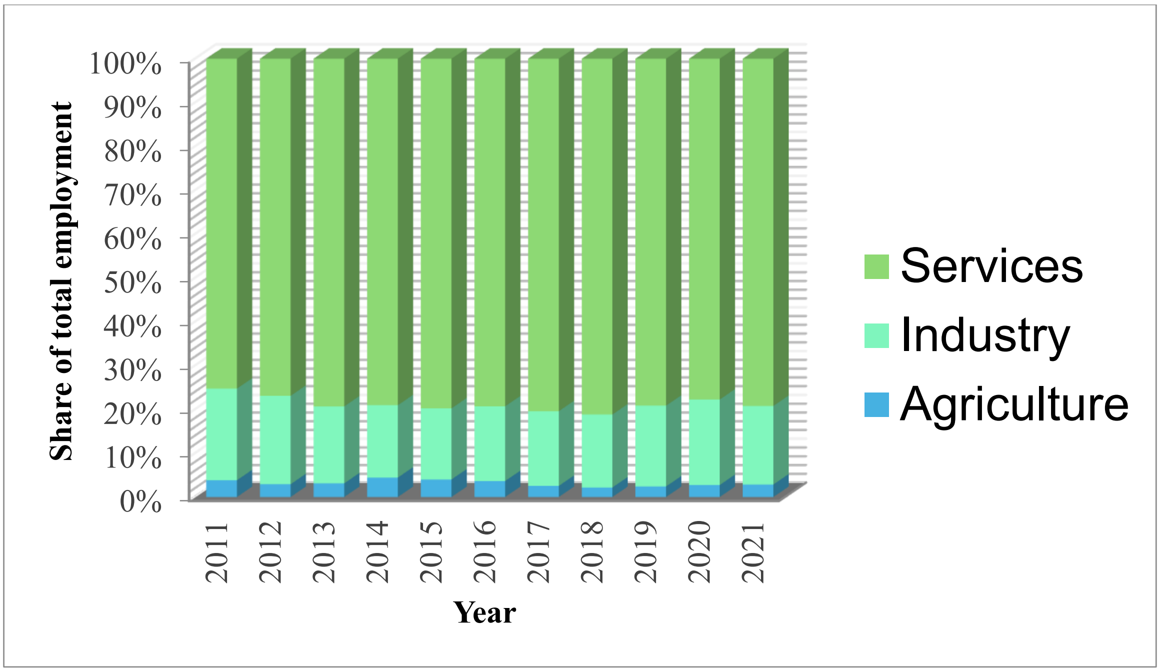

Figure 3. Distribution of employment in Cyprus by economic sector from 2011 to 2021 (data from Statista, 2024b)

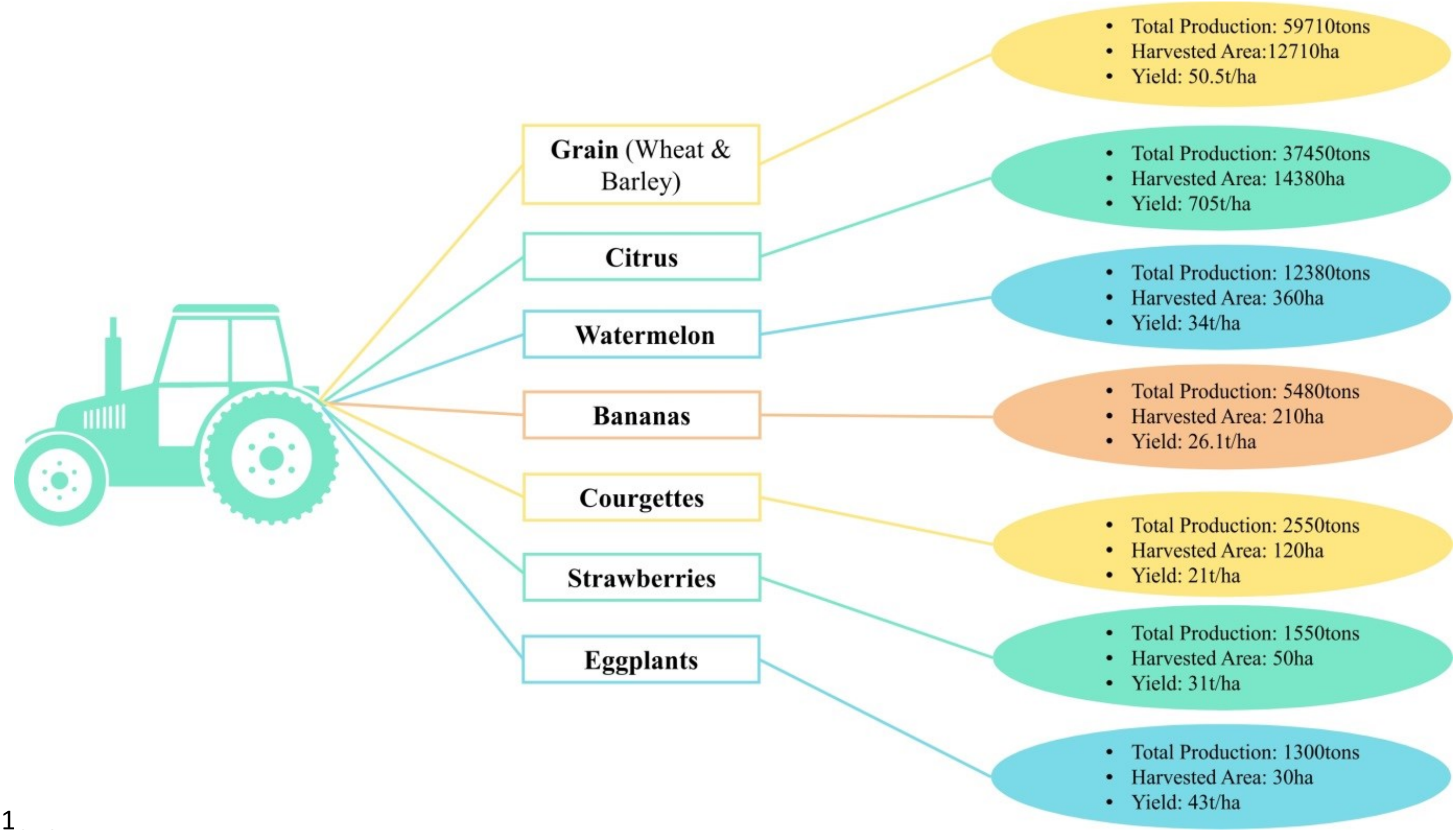

Figure 4. Crop production overview in Cyprus for the year 2022- (data from FAO (2022)

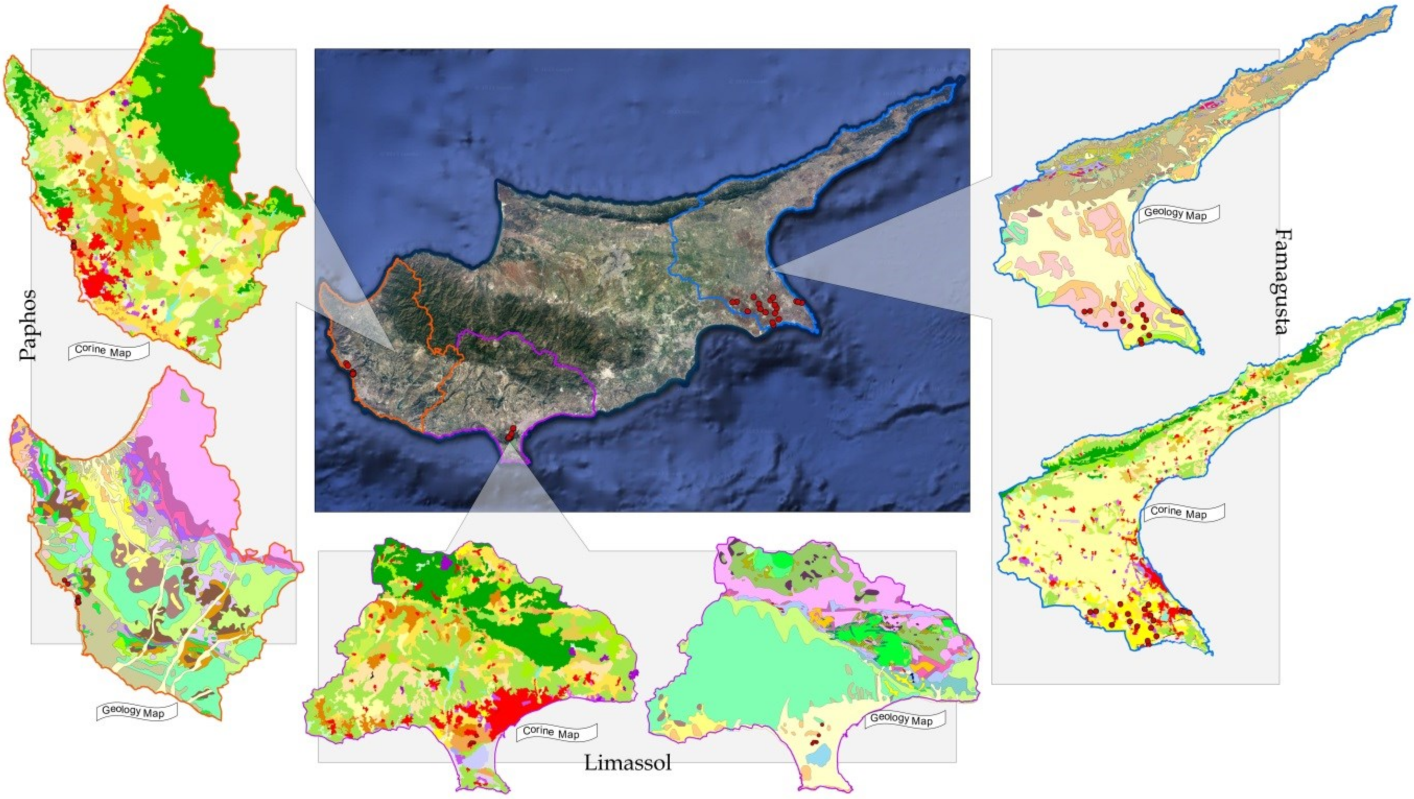

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Figure 5. Mapping of Soil Samples Location (red dots), Corine Land Cover Map of 2018 and Geology Map 1994 (CGSD, n.d.; Copernicus Land Monitoring Services, 2018)

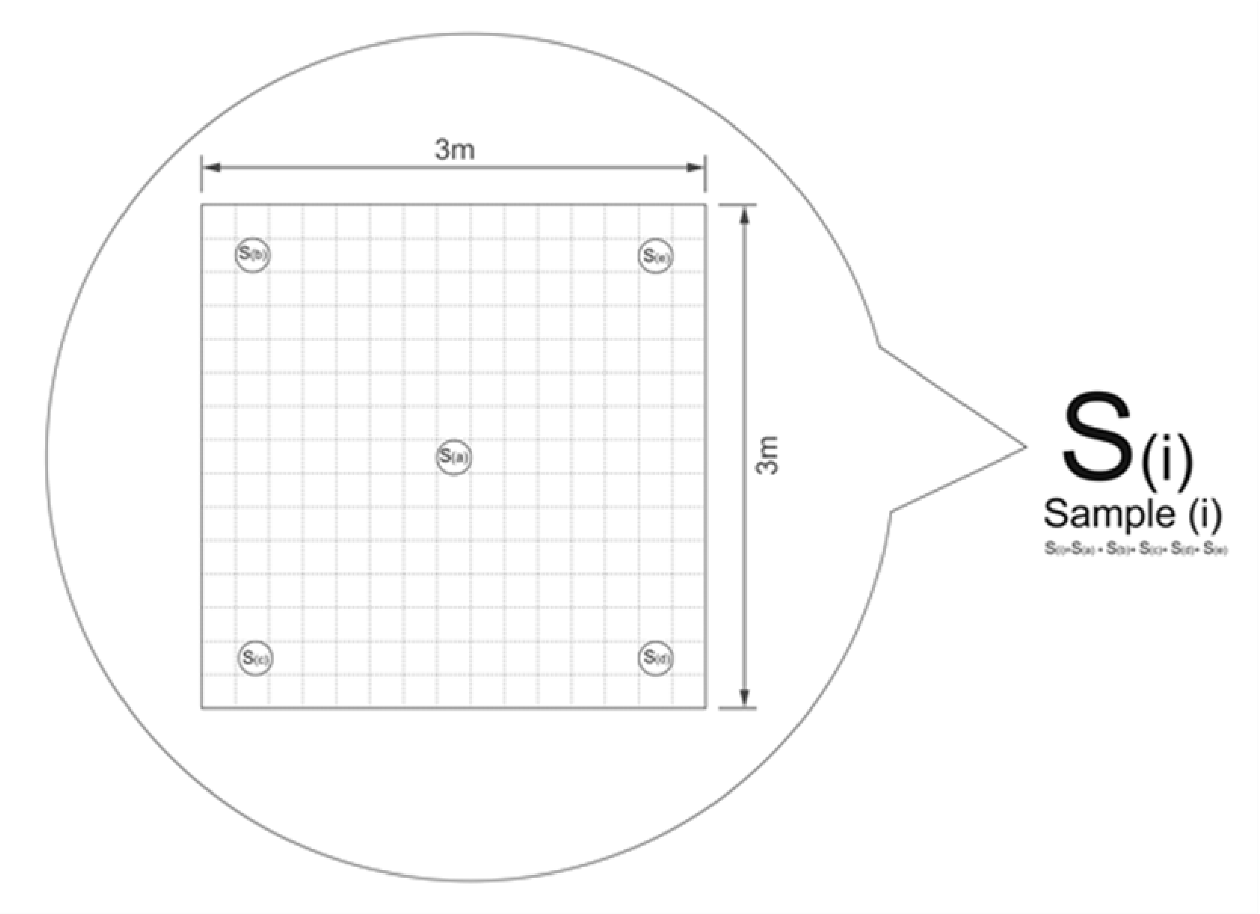

Figure 6. Schematic representation of soil material sampling per location

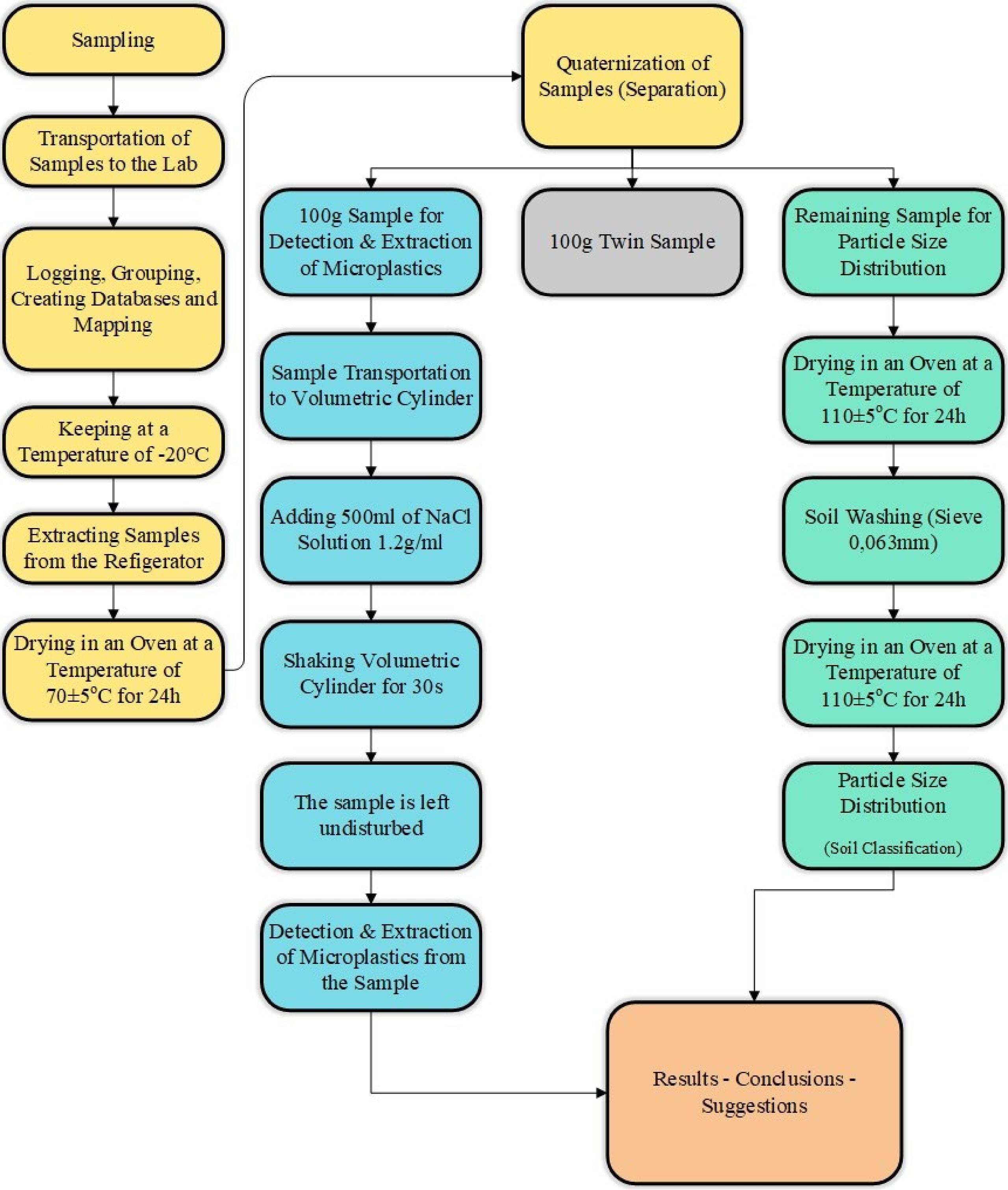

Figure 7. Methodology Analysis Following Sample Transfer to the Laboratory

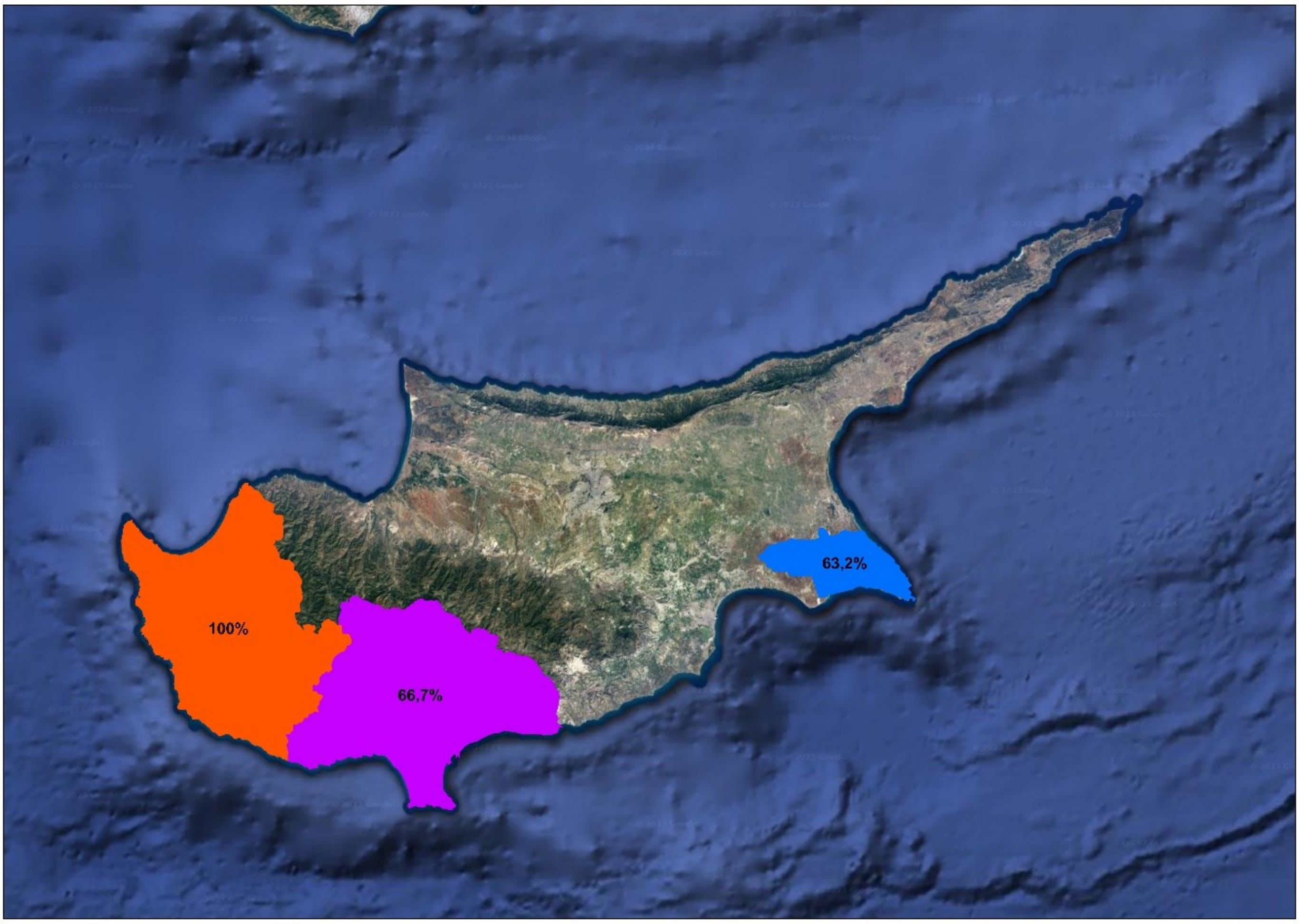

Figure 8. Percentage results of MPs from samples collected from Famagusta, Limassol and Paphos district

Figure 9. Percentage results of MPs from samples collected from the three districts, photos of the extracted MPs, as well as the crops in which they are utilized

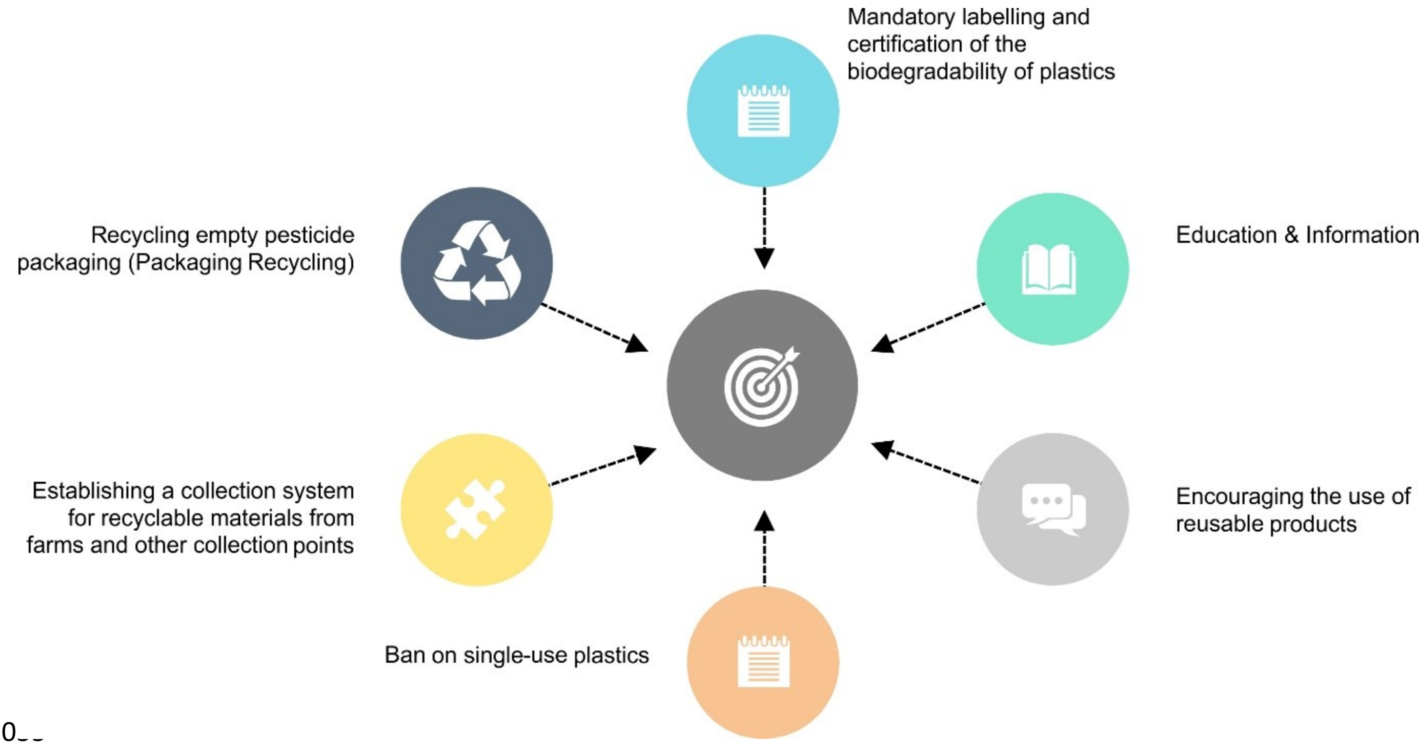

Figure 10. Strategic planning proposals for the reduction of MPs in agriculture soil