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Review

A Comprehensive Review of Plastics in Agricultural Soils: A Case Study of Castilla y León (Spain) Farmlands

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Abstract: Plastics, especially microplastics, are a diverse group of polymer-based particles, currently emerging as a global environmental threat—plastic pollution. An attempt was made to search for the presence of plastics in soils, particularly in a traditionally agricultural region such as Castilla y León (CYL). This study aimed to evaluate the use of plastics in agricultural soils in general, with an emphasis on CYL, by analyzing the present state and future perspectives on the addition of plastic waste to some agricultural soils in CYL. Surprisingly, many agricultural soils, including arable lands, irrigation, and especially greenhouse soils, receive plastic residues every day, which can lead to contaminants. By analyzing government data, we discovered that the volume of plastic waste from intensive agriculture is increasing (49,131 t in 2020) and that the current management system does not meet the needs of the sector. From this review, it can be inferred that plastics affect cultivated soils in CYL; this could affect both the economy and the soil itself and, by extension, the trophic food chain, food, and human health.

Keywords: microplastics; plastic greenhouse; plastic mulch; plastic nets; plastic waste

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1. Introduction

Globally speaking, there is a growing interest in the problem of the emergent topic of plastics in general (and microplastics and nanoplastics in particular) from scientific, public, and policy-making points of view [1–4]. Plastics are materials that consist of one or more polymer types. Polymers are chains of molecules that usually contain carbon; they can be crude-oil- or bio-based. While crude-oil-based plastics are typically made from petroleum, bio-based plastics are made entirely or partially from renewable plant-based products such as vegetable oils, corn starch, and sawdust. In general, fibers and fragments are secondary microplastics because they result from the disintegration or degradation of larger plastics. The consequence is that every day, there is more evidence that microplastics could cause environmental changes in terrestrial systems [5–8]. FAO [9] estimated that 12.5 million tons of plastic products are used for agricultural purposes annually, with films accounting for about 40 to 50 percent of this number. Usually, soil is the predominant receptor for agricultural plastic products at the end of their useful lives.

The presence of plastics, especially micro- and nano-plastics (MNPs), in the soil–food chain is already a serious multifactorial food safety problem that has drawn unusual attention from numerous scientists and organizations [10,11]. During the fifth United Nations (UN) Environment Assembly, which was held in March 2022, a historic decision was made: ending plastic pollution [12]. The decision was made by all 193 UN member states. The question now is how to achieve this goal, especially in the agricultural sector where, depending on their benefits, the use of plastic is increasing daily; this is especially relevant regarding the implications for the cycle of plastics in agriculture (Figure 1).

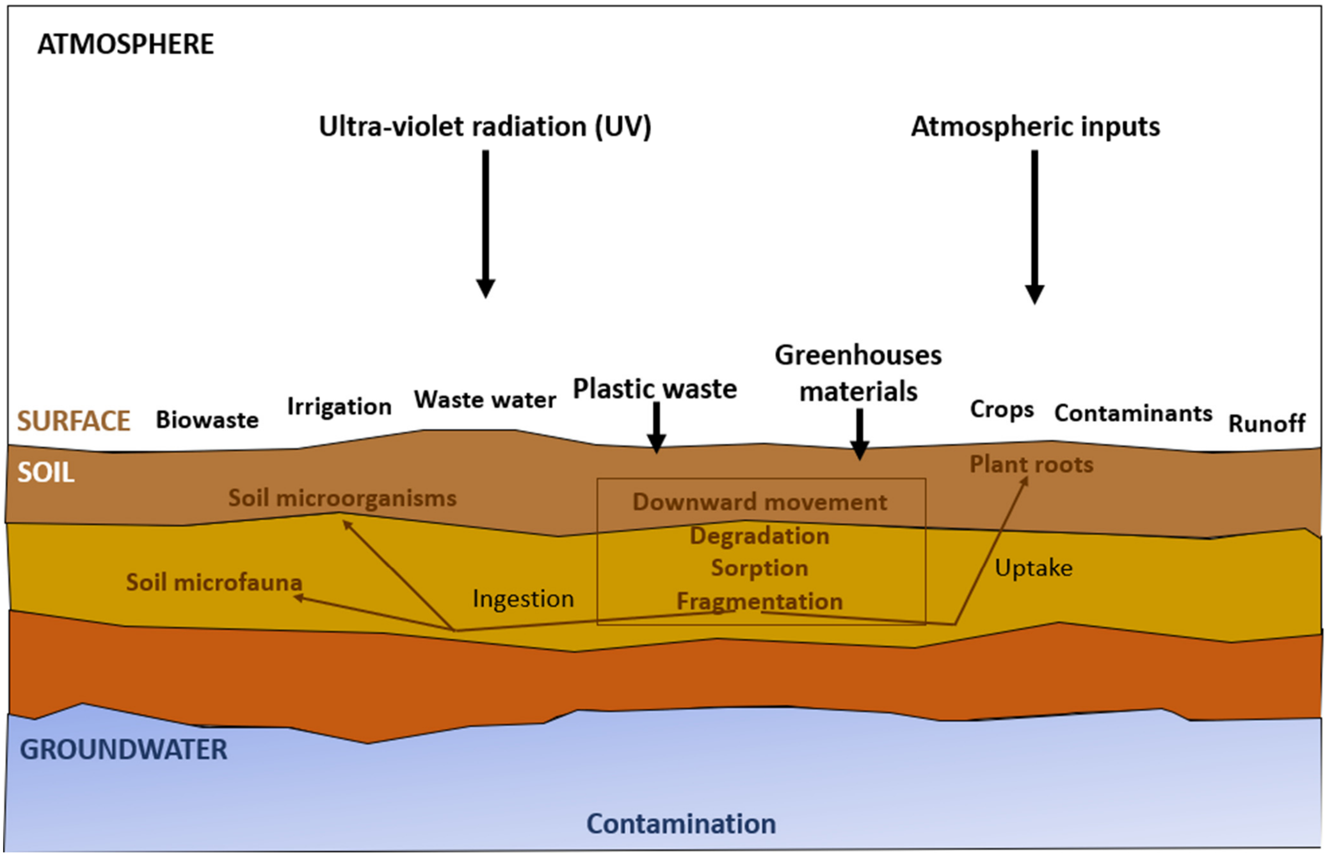

Figure 1. Cycle of plastics in agriculture (adapted from: [13]). According to these authors, plastic particles that enter the soil surface are incorporated into deep soil layers through tillage, animal activities, or water infiltration. Subsequently, plastics can be degraded by UV radiation, thermal oxidation, microbial action, or interaction with soil colloids (organic matter or clay minerals).

Abundance of Plastics in Soils

Several studies have shown that the global production of plastics has increased substantially, causing the so-called 'plastic pollution' to reach an unprecedented level [14–16]. Globally, the area of the world occupied by greenhouses at the beginning of the 21st century exceeded 450,000 ha [17].

The typology of greenhouses is varied. Based on the shapes and materials used, these houses can either be flat or vine-type, in a tunnel or semi-cylinder, in a one- or two-water chapel, with raspa or feint, asymmetrical or symmetrical, etc. [18–20].

Carus et al. [2] estimated that the global production of bio-based polymers amounted to 3.5 Mt in 2018, 3.8 Mt in 2019, and 4.2 Mt in 2020. In 2021, Plastics Europe [21] stated that 367 Mt were produced worldwide. Microplastics in Fisheries and Aquaculture [22] stated that of all plastics, microplastics (MPs) have proliferated the most; these are plastic fragment particles whose sizes range from 5 mm to 1 µm, or from 5 mm to 0.1 µm, according to He et al., and Bläsing and Amelung [23,24]. A good amount of literature [25–27] addressed plastic classification based on their size: macroplastics (>5 mm), microplastics (MP, 5000–1 µm), or nanoplastics (<1 µm) [25–27].

The greenhouses are subjected to intensive agriculture under plastic. This is especially relevant in Europe, where more than 43% of the greenhouse area in the world is located. According to a European Union (EU) report [28], 175,000 ha of the 405,000 ha greenhouses identified worldwide are located in Europe. Spain, France, Greece, Italy, and the Netherlands are the areas of greatest significance; Spain has the largest area of protected cultivation at 71,783 ha.

According to Abbate et al. [29], Spain, the United States, China, and Italy are the countries that have contributed the most to knowledge on biodegradable mulch. However, within the Spanish territory, there are certain areas that have hardly been investigated, as they are dedicated to agricultural cultivation without plastic—in fact, greenhouses are not considered a priority. One such region, where the use of plastics in agriculture is gradually increasing, is Castilla y León (CYL) [30–32].

Plastics are used in many agricultural activities such as the roofing of greenhouses and modern food storage and preservation systems. Around the middle of the last century, when they first started being used, plastics were thought to have several advantages and, as such, were very welcome. However, this initial idea has changed drastically in recent times, as different types of plastics persist in the environment as non-biodegradable micro- and nano-particles, as pointed out by [33,34] and even the European Commission's Group of Chief Scientific Advisors Environmental and Health Risks of Microplastic Pollution [35].

Since the 1960s, global production of plastics has increased 20-fold, exceeding 300 Mt in 2015; it is predicted by the EIP-AGRI Focus Group [36] and Plastics Europe [21] to double in the next 20 years. Therefore, it has become imperative to study and understand how this increase in plastics will impact the ecosystem. Many studies have been conducted on the impact of plastic pollution on aquatic ecosystems [37], but little has been investigated so far on terrestrial habitats [5,38].

Today, it is imperative to understand the occurrence and distribution of MPs in soils. Therefore, it is essential to address this issue of plastics in agriculture with the greatest possible urgency. In this context, this paper aims to evaluate existing research on plastic in general and MPs in particular, in the agro-environmental soils of CYL, in order to determine the impact of MPs on soil properties, subsidiary agricultural quality, and crop production. Thus, the main objective of this study is to evaluate the current state of studies on MPs in the agricultural soils of CYL. Overall, this review aims to highlight the most pressing research limitations in the current literature and emphasizes the future perspectives of territories traditionally dedicated to agriculture, which are now embracing modern agriculture using microplastics that end up in the soil.

2. Laboratory Methods (Extraction, Identification, and Quantification)

According to Kunz et al. [39], plastic particles are generally defined as meso-, micro-, and nano-plastics, measuring >5–<25 mm, <5–1 µm, and <1 µm, respectively. This terminology and size classification has also been established by other authors [40–43]. The greatest impact is produced by micro- and nano-particles, which is why in this study we focused on identifying these microparticles. The study of MPs in soils requires the application of various methods comprising the extraction, identification, and quantification stages [44,45], which are summarized in Figure 2. These stages involve the use of laboratory techniques to obtain information regarding the presence, type, and quantity of MPs present in a soil [44]. The extraction stage is crucial as soil particles can form stable aggregates that encapsulate and conceal the MPs, making their analysis challenging [46,47].

Therefore, it is essential to find methods that allow for the dispersion of aggregates without damaging the MPs before analysis [24,48]. Several methods are used for the extraction of MPs from soils. These include manual sieving and sorting, density fractionation using solutions, and pressure-based fluid extraction (PFE) [45,49]. Manual sieving and sorting involve visually separating MPs from a soil sample using a stereoscopic microscope. Although this method is labor-intensive and only applicable to particles larger than 500 µm, it is useful for preliminary identification of MPs [50,51].

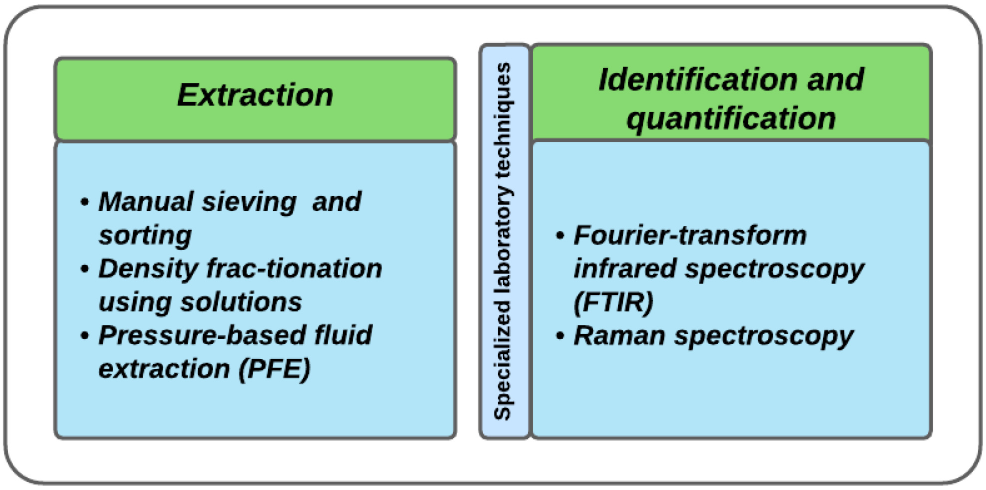

Figure 2. Laboratory procedures for analyzing microplastics in soil.

In contrast, density fractionation methods use solutions with different densities, such as water, NaCl, $CaCl_2$, $ZnCl_2$, and NaI, to separate MPs from the soil matrix [52]. However, each solution has limitations in terms of maximum density, toxicity, and interaction with the organic components of the soil [30]. Furthermore, the PFE method is effective for extracting MPs from solid samples like municipal waste and soil. This automated and cost-effective method can efficiently extract plastic particles with diameters less than 30 mm [53].

The identification and quantification of MPs in soil require specialized laboratory techniques [1,39]. For example Raman spectroscopy provides information about the molecular vibrations of MPs and can help distinguish between different types of plastics [54]. In addition, techniques such as Fourier-transform infrared spectroscopy (FTIR) and Raman spectroscopy are employed [55]. FTIR is based on the absorption of infrared radiation by the molecules of MPs, which allows for the identification of the polymers present in the sample [56,57]. These techniques enable the determination of the chemical composition of MPs and their potential origin [57]. Additionally, microscopy techniques such as scanning electron microscopy (SEM) and atomic force microscopy (AFM) are available [58]. SEM allows for high-resolution visualization of the surface of MPs, facilitating the identification of their shape and texture [59,60]. In contrast, AFM provides three-dimensional information about MPs, allowing for a more precise determination of their size and shape [61,62]. These two techniques are complementary and are used together to characterize the morphology and size of MPs present in soil samples [62]. Finally, fluorescence is a method based on the ability of MPs to emit fluorescent light when excited by a specific light source [59,63].

3. Occurrence of Plastics in Agricultural Soils: The Case of CYL

There are many possible sources of plastics in soils [64–66]. In areas traditionally devoted to intense crop cultivation in Spain (e.g., Almeria and Murcia), the use of plastic products, especially polyethylene plastic (used as crop mulches), is common. Thus, the so-called conventional agriculture uses plastics in the production of certain crops (for example, mulch, packaging, greenhouse sheds, seedbeds, and water pipes), which are frequently abandoned in the field and end up generating MPs; these MPs finally interact with a series of physical, chemical, and biological soil processes [23,48,67–69].

Indeed, agricultural activities are among the most important sources of plastic in the soil; they are often underestimated because they are difficult to quantify [70–74]. Mulch films, polymer-coated soil additives, seeds, greenhouses, polytunnels, and silage product packaging are made of plastic and are used in almost all agricultural activities. However, currently, there is hardly any knowledge about the impact of plastics on soil [75]. Figure 3 shows the main sources of plastics in soils.

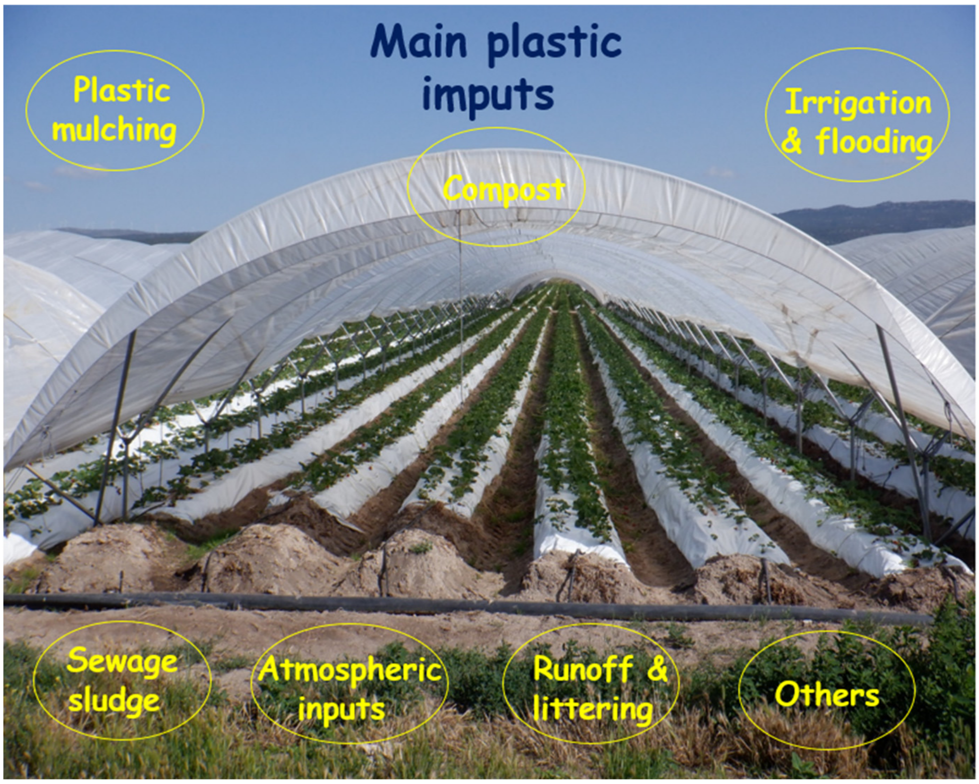

Figure 3. Main sources of plastic in agriculture soils in CYL.

Habitually, plastic protective films such as silage and bale wrap films or fumigation; protective films for mulching, nursery, wind tunnel, greenhouse, direct cover, and non-woven floating cover; twine; nets (wind breaking and shading nets, anti-bird, anti-hail); and drainage and irrigation pipes are used in the production of crops and livestock [76]. Indeed, the use of plastic mulching films is very popular among farming communities for conserving soil moisture, regulating soil temperature, and preventing weed growth. Low-density polyethylene has been applied to a large area (millions of hectares) of agricultural land worldwide [77]. Plastic films like those made of polyvinyl chloride have enhanced water use efficiency and crop growth yield.

In general, when many plastic products are detected in a soil, they exist in the form of waste deposits. Once the crop season is over, the logical thing to do would be to remove the polyethylene mulch from the field. However, for various reasons, this is not performed in reality, and even when it is done, fragments usually remain, affecting soil health. The problem is that an undesirable proportion of the plastic present in these wastes is not biodegradable and remains as waste for many years [78].

Therefore, the occurrence and abundance of plastics is closely related to silent soil management; however, this is not always the case. It has been pointed out, for instance, that a concentration of between 320 and 12,560 particles kg^{-1} exists in the superficial horizon of agricultural soils in China [79], while a mean of 320 $\pm$ 112 particles kg^{-1} exists in Mauritius [69].

In addition, other essential sources of plastics in agricultural ecosystems include biosolids (processed sewage sludge) and compost [80]. It has been observed that a predominance of microfibers is associated with soils with a history of sewage–sludge application or soils irrigated with wastewater and water from contaminated rivers [65,80–83]. Specifically, soils in which plastic mulching application has occurred contain higher amounts of MPs than soils in which no mulching has occurred [65,81,84–86].

In Spain, plastic padding is widely practiced in many areas, such as Almeria and Murcia [85–90]. The representation of greenhouses in relation to arable land in 2013 was

0.4% in Spain, 1.3% in Andalusia, 16.6% in the province of Almería, 15.8% in the Canary Islands, and 1.4% in the Region of Murcia [87]. The area dedicated to greenhouses has increased significantly in recent decades: it went from 546 ha in 1968 to 62,065 ha in 2013 [91]. What happens is that after use, they are usually abandoned for economic reasons. Similar findings have been reported in other countries by other authors such as [84,92–94].

Other possible routes of entry of plastics into agricultural soils are irrigation and organic fertilization using compost, which, in turn, is obtained from solid urban waste, manure, and sewage sludge [24,93,95]. It was long assumed that organic fertilizers would be a source of MPs. However, until now, very few studies have analyzed the plastic content in compost. The authors of [96] identified 24 MPs measuring 1 mm to 5 mm in size in German compost from municipal organic waste and green clippings. A more recent study identified approximately 2400 ± 358 MPs kg^{-1} in composts in Zhejiang Province (China) measuring between 50 µm and 5 mm [97]. Specifically, Yang et al. [93] evaluated the effect of long-term repeated application of pig manure on soils, while Weithmann et al. [96], Edo et al. [98], and Pérez-Reverón et al. [83] studied the role of organic fertilizer and wastewater in soil; finally, Corradini et al. [80] studied the effect of sewage sludge disposal.

Sewage sludge contains MPs from washed clothes, personal care products, and tires/road abrasion [80]. Therefore, when sewage sludge is added to soils, there is a real danger of incorporating plastics into the soil.

The total area dedicated to the cultivation of greenhouse vegetables in the Mediterranean basin reached up to 200,000 ha in 2010 [99]. Specifically, the province of Almería (southeast Spain), with a protected area of 30,456 ha and commercial production of fruit and vegetables valued at EUR 2537 million (tomato production corresponded to EUR 540 million), was considered to be the main hub of protected horticulture production in Europe in 2016 [100].

Global Evidence of Microplastics in Soils of Castilla y Leon

In CYL (which occupies the northern Spanish sub-plateau) (Figure 4), there are diverse soil types [101], many of which are suitable for agricultural use because they have traditionally been used for this purpose. Additionally, as in other parts of the world, certain agricultural management techniques, aimed at improving both moisture and the quality and nutritional status of the soil system, can lead to the accumulation of plastics (Figures 5–8) [66,102–105]. Therefore, this study was carried out after several consultations with the key agents involved in these techniques. In particular, the National Institute of Statistics was contacted [106]. The amount of plastic waste generated by agriculture, livestock, hunting, and forestry in CYL was 774 t in 2020, out of a total of 49,131 t in Spain (Table 1).

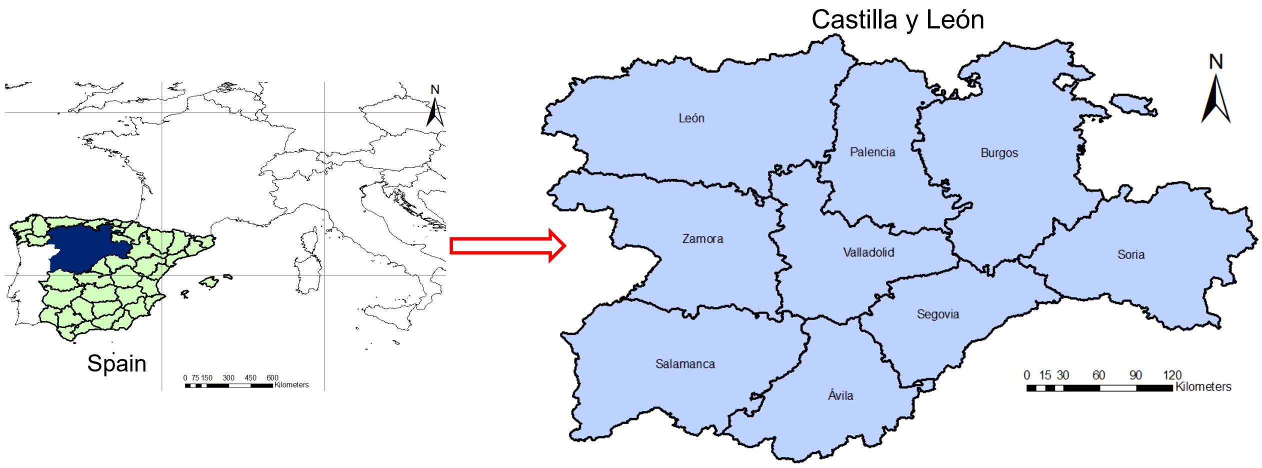

Figure 4. Location of the study area: Castilla y León region in Spain.

Figure 5. Satellite images showing the development of intensive greenhouse horticulture. Land traditionally dedicated to cereal cultivation on which plastic greenhouses are superimposed: (**a**) Cabezas de Alambre (Ávila); (**b**) Niharra (Ávila); (**c**) Solosancho (Ávila); and (**d**) Chañe (Segovia).

Figure 6. Thin plastic mulch easily tears; so, it is only used for one growing season and is almost impossible to pick up. Over time, the build-up of plastic in the soil starts to interfere with roots and water movement, reducing crop yield and cancelling out the benefits of the plastic mulch. Lettuce and cabbage cultivation. La Bañeza (León).

Figure 7. Plastic greenhouses. (**a**) Preparation of a greenhouse on Chromic Luvisols ("raña"), Matanza de los Oteros (León). (**b**) A large greenhouse in Requejo de la Vega (León), with lush forest in the background; in the first plane, crops (corn) and spontaneous vegetation. (**c**) Greenhouses are inflated structures covered with a transparent material in which crops are grown under controlled environment conditions. (**d**) The exterior of a greenhouse. (**e**) The inside of a greenhouse with a high wire system to hold the plants, located in Villamañan (Leon). (**f**) A greenhouse surrounded by a fallow Chromic Luvisol. (**g**) Greenhouses in Autillo de Campos (Palencia); notice the wheat crop. (**h**) The inside of the greenhouses in (**g**) showing cucumber crops.

Figure 8. Greenhouses in Niharra (Avila). View from inside. Plastics, in many ways, contribute positively to agriculture.

Table 1. Plastic waste generated by agriculture, livestock, hunting, and forestry by region in Spain in 2020 (Source: National Institute of Statistics) [106].

Region	Plastic Waste Production (Thousands t)
Andalucía	31.02
Aragón	0.42
Principado de Asturias	0.03
Islas Baleares	0.04
Islas Canarias	0.81
Cantabria	0.10
Castilla y León	0.77
Castilla-La Mancha	0.74
Cataluña	1.46
Comunidad Valenciana	0.85
Extremadura	0.44
Galicia	0.50
Comunidad de Madrid	1.05
Región de Murcia	8.51
Comunidad Foral de Navarra	1.04
País Vasco	0.07
La Rioja	1.29
Total Spain	**49.13**

Spain was the first country in the EU to approve the special tax on non-reusable plastic containers. Particularly, in the case of CYL, it must be noted that it is dominated (to a considerable extent) by small-scale farms. Also, most of the farmers there are over 60 years old. In CYL, there are 89 factories dedicated to the production of plastic, which employ almost two thousand people and have a turnover of nearly 400 million euros per year. There is a tendency for these factories to adapt to new manufacturing trends aimed at reducing their environmental footprint. For example, on a national scale in Spain, a very high percentage of strawberry (almost 100%) is concentrated in the province of Huelva; however, practically all the mother plants are produced in CYL. The reason for this is that strawberry initially needs a cold environment to develop and later heat to mature. Therefore, it is not surprising that in CYL there are about 35 strawberry plant nurseries, specifically in the Valladolid, Ávila, and Segovia provinces. In fact, the area dedicated to the production of strawberry plants in CYL is about 1500 ha and production exceeds 1 billion plants.

What really happens in CYL, as in many other places in the world, is that there is poor and inefficient management at the level of the farmland and the authorities responsible for agricultural plastic waste [21]. Indeed, the main source of pollution in CYL is derived from the mismanagement of agricultural plastic waste. In CYL, more residues of plastic material used to improve the productivity of agricultural crops are observed daily. This is how greenhouse covers, mulching films, irrigation pipes, etc., are observed. The use of plastic, in principle, is adequate; however, every day, more areas are observed in which plastics have been abandoned after use (Figure 9).

Figure 9. *Cont.*

Figure 9. Mulch films, once removed from fields, are often not reused—that is, they are not recyclable. Plastic abandoned in the countryside, within the municipality of Avila (**a**–**d**). (**e**–**h**) Mulch films damaged while removing crop residues. Generally, mulching films—if incorrectly applied, managed, and removed from fields—can leave large quantities of plastics in the soil, contributing to plastic contamination. Niharra (Ávila).

4. The Effects of Plastics on the Physicochemical Properties of Agricultural Soils

In general, the use of plastic nets has a series of benefits, such as reduced pests and insects. Moreover, plastic nets have proven useful in the control of *Xylella fastidiosa* and *Philaenus spumarius*, which are pests that are common in orchards and olive tree nurseries [107]. They are also used to create a unique microclimate [108].

In the literature, some authors state that plastics sometimes exert positive effects on the physicochemical properties of soil, soil microflora, and invertebrates [109–111], while other authors mention negative effects [112,113].

Although the extent of soil plastic pollution and its short- and long-term impact are relatively unknown, it is considered that micro(nano)plastic is a physical soil contaminant that can lower soil bulk density; potentially reduce root penetration resistance; and increase soil aeration, soil water movement, and water evaporation. It can even modify soil aggregation and release (toxic) plastic leachate into soils [114]. A substantial amount of the literature addresses several factors, such as irrigation, plastic mulching, soil amendments, flooding, and diffuse and urban runoff, which may result in the penetration of microplastics into soils [3,6,8,13,43,67,104,115,116].

De Souza et al. [67,117] stated that physicochemical characteristics of soil, such as water-holding capacity, soil bulk density, soil structures, and soil pH, can be altered by the decomposition of microplastics in soil aggregates. According to the previously cited authors [67,117] and Wang et al. [118], the presence of microplastics in terrestrial ecosystems may harm plant performance, microbial activities, and soil characteristics.

Others [119–122] have stated that plastics can impact the chemical (pH, CEC, etc.), physical (soil bulk-density, porosity, aggregate formation, water distribution availability, etc.), and biological properties of the soil. In this context, Boots et al. [38] stated that increasing soil microplastics generally results in a reduction in soil pH, while Ween et al. [123] stated that microplastics increased the residue fraction of Pb, Cd, Cu, and Zn.

The potential impact of MPs on soil microbial diversity and degradation has also been reported [124]. In any case, it is convenient to highlight the possible consequences of plastics on food-crop production.

Globally, it is known that the accumulation of plastics in soils affects their physical, chemical, and biological properties, including bulk density, porosity, water retention capacity, hydraulic properties, soil conductivity, specific surface area, pH, cation exchange capacity, etc. [125–131]. The impact of plastics on a series of soil processes such as nitrification, structuring, hydraulic characteristics, and evaporation has also been cited.

Some studies suggest that, regarding the vertical distributions of MPs, the tendency is to accumulate in shallow soil; however, some other authors state that more MPs are found in deeper soil layers [81,132], and differences have been pointed out depending on the type of soil [83]. In any case, as shown in Figure 10, plastics affect a series of parameters that ultimately impact both soils and crops.

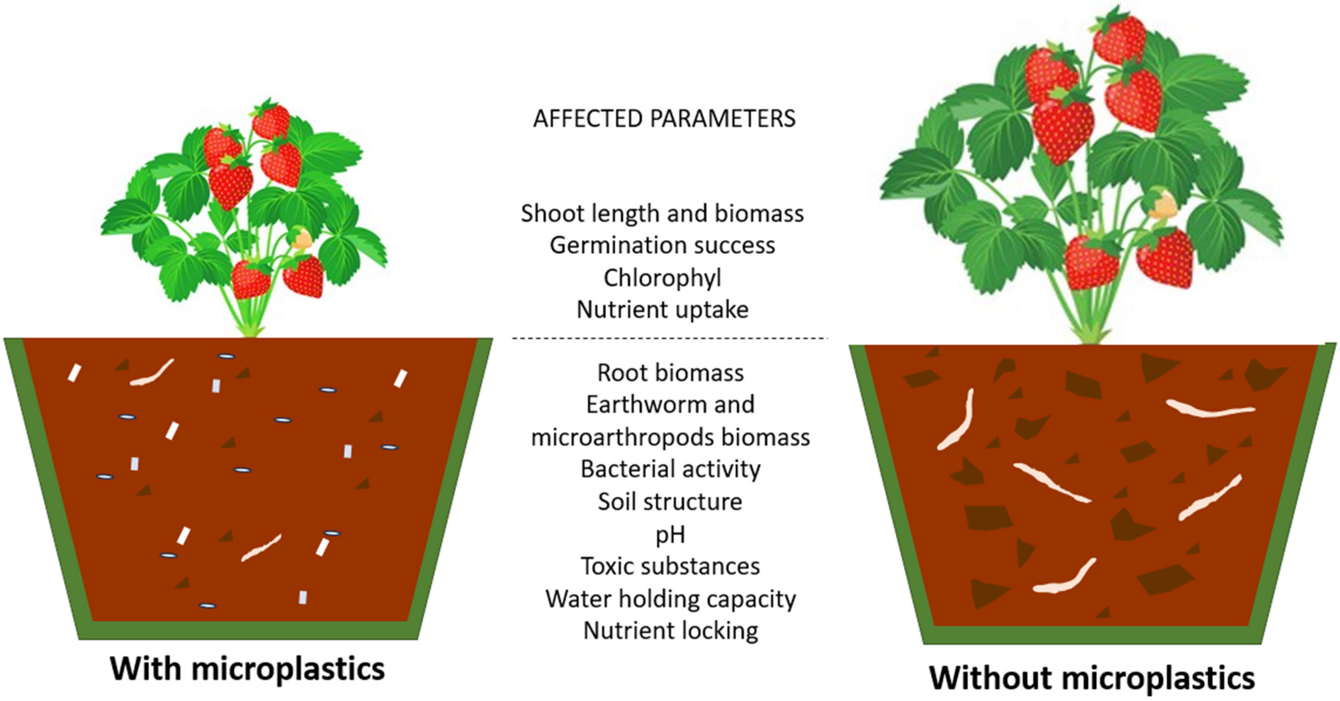

Figure 10. Effects on soil and crops of microplastics in the soil (adapted from [38]).

Obviously, due to the low density of MPs compared with those of many natural soil minerals, an increase in MPs entails a decrease in density. Moreover, MPs affect the chemical properties and functional groups of dissolved organic matter [133]. Up to 6% of MPs reportedly reduce the saturated hydraulic conductivity of sandy, clay, and loamy soils by 96, 77, and 70%, respectively [128]. Furthermore, the addition of MPs generated a more important decrement in the water retention capacity of clay soils than in that of sandy and loamy soils.

MPs also impair soil stability, which influences the stability of aggregates and reduces water infiltration into the soil. Some studies have reported the adverse impacts of MNPs on the chemical and physical properties of soil, such as organic matter, nutrients, pH, structure, porosity, bulk density, and water content [134–137].

Regarding the impact of biodegradable mulches on soil properties, it should be noted that, in general, mulches affect many soil properties including structure, moisture, and water/air ratio. In particular, mulches exert an effect on soil temperature and its reactions [138–141]. However, this effect of mulches is conditioned by the nature of the material from which they are made, their transparency to solar radiation, and their thickness.

5. Potential Susceptibility of Two Benchmark Soils of CYL to Plastic Pollution

Given the backdrop of soil plastic pollution, the spatial reference of soil context data becomes important. From a soil geography perspective in CYL, its soils, as a potential reservoir for plastics, should be conceptualized as a three-dimensional, spatial phenomenon—a fact already highlighted by Weber et al. [142].

Soils in the CYL territory exhibit distinct characteristics caused by soil-forming factors. Understanding the nature of these soils and documenting their properties can help combat microplastic pollution in CYL soils. Benchmark soils, characterized by their extensive data and importance to land use, play a role in estimating the potential susceptibility of two benchmark soils in CYL.

A reconnaissance field survey was conducted during the last decade using transect walks, auger observations, and descriptions to establish two benchmark soils. The soils were sampled at the end of August 2023. The profiles were identified, excavated with standard dimensions (approximately 1.5 m width and 2 m length), and described according to FAO Guidelines for Soil Description [143].

In the laboratory, soil samples were air-dried, ground to pass through a 2 mm sieve, and prepared for the determination of soil parameters. Soil texture was determined using the hydrometer method [144] with three replicates. Soil pH was potentiometrically measured in H_2O using a 1:2.5 soil:water suspension. Electrical conductivity was measured using an EC meter in a 1:5 soil:water extraction. Calcium carbonate was measured using the calcimeter Bernard method. Soil organic matter was determined using the dichromate method; total nitrogen was measured by Kjeldahl's method [145]. Cation exchange capacity was measured by means of ammonium acetate [146] and determined by atomic absorption spectrometry. Available phosphorus was measured by extraction using alkaline sodium bicarbonate. Bulk density was determined by the cylindrical method [147]. All samples were extracted and analyzed in triplicate.

The results obtained are presented in Table 2. It is evident that the attributes of the two benchmark soils in the table are clearly different. Thus, while the effect of plastic can vary based on the extent of exposure, quantity, type, and size of the MPs, a different susceptibility to the addition of plastics can be predicted.

The presence of MPs in soil has been reported to change soil chemical properties such as soil organic matter (SOM) content, pH, electrical conductivity (EC), apparent density, ion exchange capacity, and organic carbon storage (by impact on, e.g., soil microbial processes or litter decomposition) [117,148–150]. The La Bureba profile, located in the province of Burgos, develops on continental tertiary loamy sediments that emerge in the region, highlighting its powerful horizon of enrichment in organic matter (isohumic character). We classify this profile as Typic Calcixeroll [151]. Meanwhile, the Casavieja profile (located in the province of Ávila), classified as Typic Dystroxerept, develops on granitic materials at the base of the Sierra de Gredos. It is clear that these profiles have distinct properties. The Mollisol of the Bureba profile has high fertility, and excellent water dynamics and air permeability, making it suitable for plant and animal life. The soil structure is associated with great aggregate stability, soil water movement and retention, low erosion, ease of root penetration, and high crop yields [152,153]. In contrast, the Dystroxerept soil is sandy-loam/loam-sandy and develops from granite parent material. The profile has different characteristics with a lower SOC concentration, TN concentration, Olsen phosphorus concentration, and a more basic pH. Its structural stability is lower, and its permeability is reduced. In the case of Calcixeroll, plastic fiber addition probably does not negatively affect the formation of aggregates (due to its cushioning properties), while for Dystroxerepts, it does. In other words, plastic fiber contamination likely does not affect surface runoff and drainage in one case, while it does in the other. In simple terms, the tendency of microplastics to decrease soil erosion increases as the soil becomes intrinsically more erodible, and these two soils are indeed different due to the presence of a deep mollic horizon in the Calcixeroll profile.

Table 2. Pedological characteristics of the investigated soils.

		Typic Calcixeroll (La Bureba, Burgos)			Typic Dystroxerept (Casavieja, Ávila)		
		A_{h1}	A_{h2}	C_k	A_h	B_w	C
Site Coordinates UTM (30S)		478,189; 4,712,461			348,799; 4,460,559		
Depth (cm)		0–18	18–69	>69	0–21	21–89	>99
Coarse elements (%)		8.9	6.7	3.2	24.0	11.4	12.7
Sand (%)		50.7	55.1	44.7	74.2	81.7	79.7
Silt (%)		25.0	20.6	30.5	16.5	11.0	14.0
Clay (%)		24.3	24.3	24.8	9.3	7.3	6.3
Texture		Sandy Clay Loam	Sandy Clay Loam	Loam	Sandy Loam	Loam Sandy	Sandy Loam
Organic Matter (%)		4.8	3.7	0.1	1.2	0.4	0.1
P (mg/kg)		14.4	10.6	4.2	9.5	6.8	0
Total Nitrogen (%)		0.15	0.16	0.10	0.04	0.02	0
C/N ratio		18.6	13.4	0.5	17.25	11.5	n.d.
pH (water 1:2.5)		7.6	7.7	8.4	6.0	6.1	5.5
Electrical conductivity (dS/m)		0.23	0.27	0.22	0.12	0.13	0.07
$CaCO_3$ Content (%)		28.0	23.0	44.0	0	0	0
Bulk density (g/cc)		0.9	0.8	1.5	1.3	1.6	1.7
Cation Exchange Complex ($cmol^+/kg$)	Ca^{2+}	38.3	44.0	47.2	2.6	1.8	1.2
	Mg^{2+}	1.7	1.5	1.1	0.7	1.3	1.3
	K^+	0.1	0.1	0.1	0.2	0.1	0.1
	Na^+	0.1	0.1	0.2	0.1	0.1	0.1
	CEC	38.7	43.4	35.2	18.9	24.0	16.0
S (Sum of cations)		40.2	45.7	36.6.	3.6	4.3	3.7
Base saturation (%)		100	100	100	19.0	17.9	23.0

6. Conclusions, Prospects, and Research Gaps

This work represents a turning point in the extensive use of plastics in agriculture in CYL, which can lead to the generation of large quantities of waste. Many agricultural practices and amendments are currently generating soil contamination by plastics. There is increasing evidence that these plastics contribute to soil pollution. Indeed, agricultural activities such as crop rotation or mechanical tillage can accelerate the fractioning of MNPs [154], which implies their release into the soil. MNPs contaminate soil by two different mechanisms: first, by releasing their toxic compounds [153], and second, by acting as vectors for other pollutants [154].

The use of plastics in agriculture in CYL is increasing on a daily basis; this implies a benefit in terms of agricultural production. However, the misuse of plastics after agricultural operations can lead to plastic waste and consequent environmental contamination by plastic debris. After more than two decades of microplastic addition to soils, it has become obvious that soil systems act as a reservoir for microplastics. The challenge is reducing the plastic footprint in agriculture to maintain the health of soils that are already very productive, at least traditionally.

To the best of our knowledge, research on the impact of MPs on agricultural soils of CYL is limited. There are hardly any experimental studies on this topic. Therefore, although data regarding this type of study are practically limited to the beginning of the last decade, studies on the effect of MPs on soil fauna, vegetation growth, microorganisms, and bio-geophysical and chemical properties should be initiated. From the field work carried out in CYL for this study, it was deduced that the potential sources of MPs were mainly plastic mulching film, wastewater irrigation, and application of organic fertilizer. In any case, faced with this challenge, one of the specific objectives indicated by FAO [9] is to protect the soil ecosystem from excessive plastic pollution. The behavior of the soils analyzed in the presence of microplastics is markedly different. In Calcixeroll, the addition of plastic fibers will not negatively affect the aggregates; therefore, runoff and erosion will not increase because the deep mollic horizon acts as protection. However, in Dystroxerept, water infiltration and runoff will be negatively affected [92].

Some steps should be taken in CYL. First, a study on the identification of zones or areas that are today intensively affected by the use of plastics in agriculture should be conducted.

Second, studies should be carried out with the aim of achieving standardized methods for collecting, extracting, identifying, and quantifying MNPs in agricultural soils, taking into consideration the nature of the different types of soils and their properties.

We make the following recommendations:

1. Avoiding the use of plastics by adopting more sustainable agricultural practices, in such a way that it is necessary to try to eliminate the use of unnecessary or problematic plastics;
2. Replacing greenhouse films and unnecessary plastics with more durable alternatives, such as glass or polycarbonate, and safe and sustainable materials;
3. Replacing short-term, single-cycle products with reusable ones, e.g., stackable rigid harvesting crates instead of flexible bags;
4. Replacing non-biodegradable conventional polymers with biodegradable polymers.

From the review carried out, it can be concluded that there has been a true explosion of knowledge (particularly in the last two decades) about plastics in agricultural soils. It is perhaps for this reason that the subject has not yet been fully understood, in such a way that future research will need to focus on impact assessments in soils. Keep in mind that the actual climatic change will bring higher temperatures, solar radiation, and less precipitation, over a partly semi-arid region, which will facilitate the physical weathering, aging, and quality deterioration of plastic films. This article represents a synopsis of regional microplastic concentrations, and a turning point for the increasing and uncontrolled plastic production in the agriculture of soils in CYL, highlighting the possible pollution in the environment.

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