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Distribution and Characteristics of Microplastics in Plastic-Mulched Farmland in Wringinanom Subdistrict, Gresik

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Keywords

Plastic Mulch; Microplastics; Soil; Agriculture

Abstract

The use of plastic mulch in agriculture continues to increase to improve efficiency and productivity. However, long-term application may leave plastic residues that degrade into microplastics. This study analyzed the vertical distribution and characteristics of microplastics in agricultural soils in Wringinanom Subdistrict. Sampling sites were selected purposively, and microplastic distribution was analyzed descriptively. Mulched fields showed higher microplastic abundance than non-mulched fields. The presence of microplastics at depths >20 cm indicated vertical migration within the soil profile. Fibers were the dominant form, accounting for 52–87% of detected particles. Most microplastics were 0.05–0.1 mm in size, while 67% were black. Microplastic accumulation may adversely affect agricultural soil quality. Therefore, organic mulch, cover crops, and biodegradable mulch should be considered as more sustainable alternatives.

INTRODUCTION

The increasing use of plastics across various sectors has raised concerns about the accumulation of persistent plastic waste. Microplastics, defined as plastic particles smaller than 5 mm, can originate from the degradation of larger plastic debris and are easily transported by water and wind, potentially causing adverse environmental impacts (Laksono et al., 2021). Based on their source, microplastics are classified as primary and secondary; primary microplastics are produced directly in the form of microscopic particles, such as beads in skin care products, while secondary microplastics originate from larger plastic fragments that have undergone degradation (Purnama et al., 2021). Both types of microplastics are widely dispersed in various forms resulting from human activities, both domestic and industrial. Common forms of microplastics include fragments, films, fibers, pellets, and foam (Murtadho, 2023). Fragments are commonly found in broken pieces of plastic bottles, jars, or mica sheets; fibers originate from the degradation of synthetic clothing; films result from the degradation of plastic bags and food packaging; pellets are found in personal care products such as facial scrubs and toothpaste; and foam forms from the degradation of single use styrofoam. Microplastics have been detected in various environmental matrices, including air, water, and soil. The presence of microplastics in the environment is a serious concern due to their persistent nature, slow degradation, ability to bind toxic compounds, and potential to enter the food chain. Widianarko & Hantoro (2019) state that some plastics contain and release hazardous chemicals, and microplastics can attract and accumulate these substances from their surrounding environment.

The plastic use in the agricultural sector continues to rise in line with the need for efficiency and productivity, including the use of plastic mulch.

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According to Hasibuan (2021), mulch is a material used to cover the soil surface to retain soil moisture, suppress weed growth, and reduce the risk of erosion. Plastic mulch is the most commonly used type because it is considered effective at controlling weeds, maintaining soil temperature, and reflecting light to reduce pest infestations. Gulo *et al. (2025)* add that plastic mulch can improve farming efficiency by reducing evaporation and increasing crop yields. Long term use of plastic mulch carries the risk of leaving plastic residues in the soil, despite its significant benefits. These residues can degrade under sunlight and rain, leading to the mulch producing microplastics (Nugraha, 2024). These fragmented microplastics will be distributed both on the soil surface and within the soil layers over time.

Wringinanom Subdistrict is one of the subdistricts in Gresik Regency, located at an elevation of approximately 11 meters above sea level (masl) with an average annual rainfall of about 1,909 mm (Badan Pusat Statistik, 2024). Wringinanom Subdistrict borders Kedamean Subdistrict to the north, Driyorejo Subdistrict to the east, Sidoarjo Regency to the south, and Mojokerto Regency to the west (Dewitasari, 2016). Agricultural activities in Watestanjung Village are classified as intensive and frequently involve the use of plastic mulch in horticultural cultivation. This area is known as a center for horticultural agriculture, particularly for commodities such as chili peppers, eggplants, and melons. The types of mulch used in several areas of Wringinanom Subdistrict are silver plastic mulch and plastic mulch made from sachet waste. The plastic mulch made from sachet waste and silver plastic mulch widely used in the Wringinanom area primarily consist of synthetic polymers such as polyethylene (PE) and polypropylene (PP), which are resistant to natural degradation (Wibisono, 2024). Sachet waste used as raw material for mulch generally comes from packaging of everyday consumer products containing a mixture of plastic and aluminum. In contrast, silver plastic mulch typically has a reflective layer made of polyethylene. The surface of the mulch can gradually degrade into small particles due to exposure to ultraviolet light. These fragments have the potential to become microplastics that can enter and accumulate in the soil, thereby triggering damage to ecosystems and soil fertility in agricultural land, which in turn hinders agricultural processes (Brata, 2024).

Research on microplastics in agricultural soil in Indonesia remains very limited, particularly on land where plastic mulch is used. A comprehensive review by Kumar *et al*. (2020), identified that plastic mulch can be a source of microplastic contamination in soil in addition to irrigation water; however, this review did not further elaborate on how deep plastic mulch residues can migrate or how the characteristics of microplastics change at different soil depths. Research on the distribution of microplastics at various soil depths was previously conducted by Huang *et al.* (2020), but that study did not compare microplastic characteristics across soil depths. A study by Long *et al.* (2023), microplastic characteristics but did not address their distribution at different soil depths. That study also utilized advanced systems such as the Laser Direct Infrared (LDIR) Chemical Imaging System, capable of revealing microplastic abundance at high resolution; however, the availability of this equipment is limited, so further research using more common and accessible methods is still needed.

Plastic mulch is widely recognized as a potential source of microplastic contamination in agricultural soils. However, information on the distribution and characteristics of microplastics in mulched agricultural soils remains limited, particularly in Watestanjung Village, Wringinanom Subdistrict. This study aims to (1) assess the vertical distribution of microplastics across different soil depths and (2) characterize microplastics found in agricultural soils under plastic mulch application.

RESEARCH METHODS

This study was conducted in July 2025 by collecting samples from agricultural land that uses plastic mulch made from sachet waste and silver plastic mulch in Watestanjung Village, Wringinanom Subdistrict, Gresik Regency. The study collected a total of 18 samples, with three sampling points at each location. Soil samples were collected at two depths: 0–5 cm and greater than 20 cm at each sampling point. This analysis was conducted to assess the vertical migration of microplastics within the soil (Fakour et al., 2021). The soil samples were analyzed at the ECOTON laboratory located in Krajan Hamlet, Wringinanom Subdistrict, Gresik Regency, East Java.

The sampling locations for the microplastic observation in soil were determined using the purposive sampling method. This method was chosen because it allows for precise sampling at locations aligned with the research objectives (Subhaktiyasa, 2024). Locations were specifically selected on agricultural land using plastic mulch, as this is suspected to be the primary source of microplastics in the soil. The Gresik region, particularly Wringinanom Subdistrict, possesses unique characteristics not found in other areas. Some farmers in Wringinanom Subdistrict use sachet waste as a soil cover material. This practice is quite interesting from the perspective of local innovation, but it also raises concerns about the potential for higher microplastic contamination, as sachet waste typically consists of multilayer structures that are difficult to degrade. However, the observations were not limited to fields using sachet waste mulch. The study also included observations of fields using silver mulch to determine whether silver mulch poses a lower risk than sachet waste mulch in terms of microplastic content.

The equipment used in this study included glass beakers, a 5 mm sieve, Petri dishes, glass containers, dropper pipettes, spatulas, measuring cups, a stereo microscope, an oven, a stirring rod, a glass funnel, a digital scale, a vacuum filtration apparatus, and a fume hood. The materials used in this study were distilled water, aluminum foil, label paper, a filtering membrane, petroleum jelly, tissues, 30% H_2O_2, Fe_2SO_4, NaCl, and the collected soil samples.

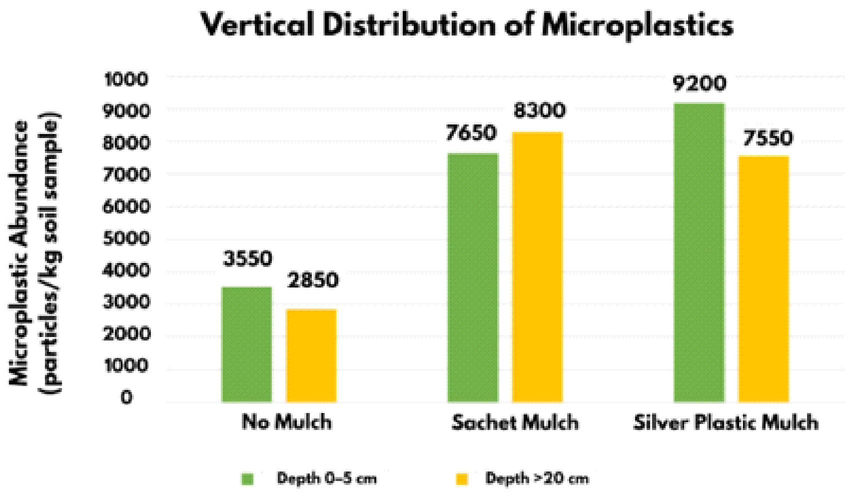
The microplastic extraction process from the soil began by drying the soil samples in an oven for 4 hours at 100 °C, followed by grinding the samples to break up clump and sieve them through a 5 mm sieve to remove large contaminant particels. Twenty grams of the sieved soil sample were placed in a beaker, and 40 mL of NaCl solution (twice the volume of the soil sample) was added. The mixture was stirred and allowed to stand for 24 hours to allow the soil particles to settle completely. The supernatant was transferred to a new container, and 20 mL of 30% hydrogen peroxide (H_2O_2) and 0.25 mL of Fe2SO_4 were added to decompose organic matter; the mixture was then incubated in a fume hood for 24 hours (Larasati, 2024). Microplastic filtration was performed using a vacuum filtration apparatus.

The microplastic particles retained on the filter were subsequently transferred to a Petri dish for further identification. Microplastics were identified using a stereo microscope with a magnification of 40–400x via the visual method (Huang et al., 2020). The stereo microscope was connected to a computer via Optilab Viewer 2.2 software, which allowed for the capture of images of microplastics visible under the microscope. Observations of the color, shape, abundance, and size of microplastic particles were conducted using Image Raster software. The observation data were recorded and processed using Microsoft Excel. Microplastic abundance was calculated using the formula from (Sulastri et al., 2023).

$$C=\frac{n}{M} \tag{1}$$

where C is microplastic abundance (particles/kg), n is number of pieces (particle), and M is mass of dry sediment (Kg).

Microplastic distribution at each soil depth was determined using a descriptive method. This method was



Source: Processed Research Data, (2025)
Figure 1
Vertical Distribution of Microplastics

chosen because it can describe, analyze, and compare the overall data based on the actual research findings (Rengkuan et al., 2023). The data obtained were analyzed qualitatively and quantitatively to provide a comprehensive picture of the potential for microplastic contamination in agricultural soil resulting from the use of various types of mulch.

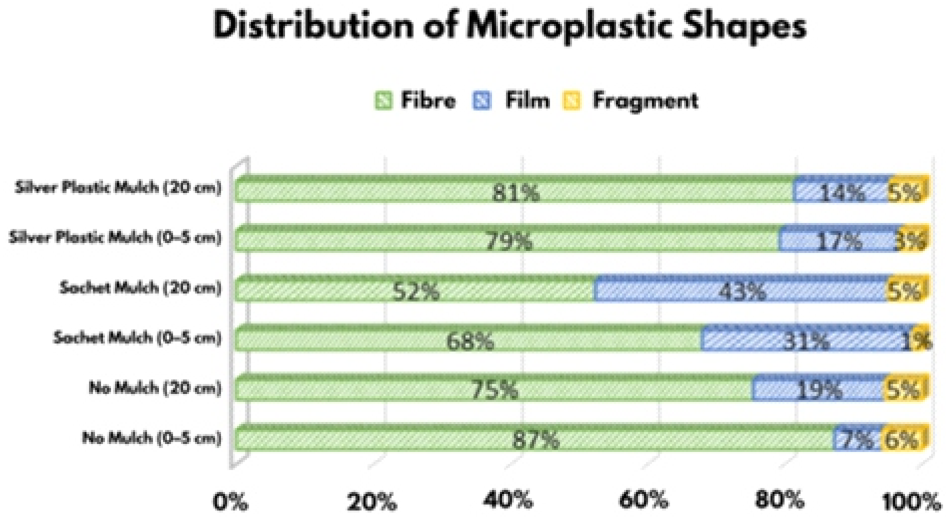
RESULTS AND DISCUSSION

The results of the observations show that microplastics were found in all soil samples from agricultural land in Watestanjung Village. Microplastics were found at depths of both 0–5 cm and >20 cm, indicating the potential for particle migration to deeper soil layers. The vertical distribution of these microplastics is presented in more detail in Figure 1.

Figure 1 presents the abundance of microplastic particles in agricultural land. The results show that fields using mulch, whether sachet mulch or silver mulch, exhibit higher microplastic abundance compared to non-mulched fields. This may occur because the primary source of microplastics in non-mulched fields is limited to off-site residues. Conversely, in fields using mulch, sources of microplastic contamination also originate from the mulch materials themselves, which are made of plastic. The primary components of mulch consist of synthetic polymers such as polyethylene (PE) and polypropylene (PP), which are resistant to natural degradation (Wibisono, 2024).

Microplastics were found in all plots and at all soil depths, both at depths of 0–5 cm and at depths >20 cm. Microplastics are generally more prevalent in the surface layer. The microplastic level in non mulched plots was 3,550 particles/kg of soil at a depth of 0–5 cm, while at depths >20 cm, it was 2,850 particles/kg. A similar pattern was also observed in silver-mulched plots, where microplastic concentrations were 9,200 particles/kg of soil at depths of 0–5 cm, while at depths greater than 20 cm, they were 7,550 particles/kg. However, in the sachet-mulched plots, microplastic abundance was higher at depths >20 cm 8,300 particles/kg of soil compared to 7,650 particles/kg of soil at depths of 0–5 cm. The presence of microplastics at depths >20 cm confirms the occurrence of vertical migration of microplastics into deeper soil layers. This finding aligns with the study, which reported that the use of plastic mulch not only increases microplastic abundance in the surface layer but also contributes to particle accumulation in deeper soil layers due to water infiltration and soil tillage activities.

Figure 2 presents data on the dominance of microplastic forms in agricultural land. Identification results



Source: Processed Research Data, (2025)

Figure 2

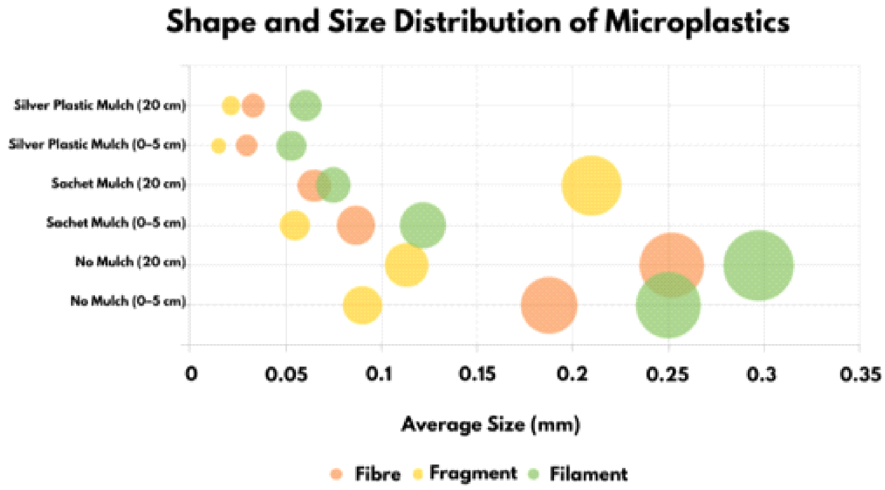
Distribution of Microplastic Shapes

show that the microplastic forms found across all land uses consist of fibers, films, and fragments. In general, the most dominant microplastic form is fibers, ranging from 52–87% of the total identified microplastics across all land use types and at all depths. Film was the second most dominant form, ranging from 7–43%, and showed increased prevalence on land where mulch was used. Meanwhile, fragments were found in small quantities across all land-use types, with percentages ranging from 1–6%.

The predominance of fiber-shaped microplastics indicates that the primary source of microplastics in agricultural land is not limited to the degradation of plastic mulch. Fiber microplastics may originate from irrigation water contaminated with domestic wastewater, agricultural plastic ties, and atmospheric deposition (G. S. Zhang & Liu, 2018), suggesting contributions from activities other than mulch use. On the other hand, the increase in the percentage of film shaped microplastics in fields using sachet mulch may indicate that the degradation of plastic mulch is a significant source of microplastics in agricultural soil. This finding is consistent with the study, which reported that film like microplastics are the most common type found in agricultural fields using plastic mulch, accounting for 33–56% of the total microplastics detected in the soil.

The data shown in Figure 3 indicate that microplastic content across various agricultural land treatments consists of three main types: fibers, fragments, and filaments. These three types of microplastics are distributed across both mulched and non-mulched land treatments, as well as at different soil depths. Based on the study, the largest microplastics had an average size of 0.3 mm and were in the form of fragments and filaments, while the smallest microplastics measured 0.05–0.1 mm and were in the form of fibers and filaments. These size differences indicate a degradation process in which medium- to large sized particles form first before breaking down into finer particles. The smaller the resulting microplastics, the easier it is for them to migrate to deeper soil layers.

The formation of these size variations aligns with Figure 4 regarding the degradation mechanism of plastic mulch in soil. UV exposure causes the breaking of polymer bonds, while physical factors such as wind and rain can accelerate mechanical damage through abrasion and tearing forces. Larger particles form in the early stages and gradually become smaller as oxidation, mechanical stress, and interactions with



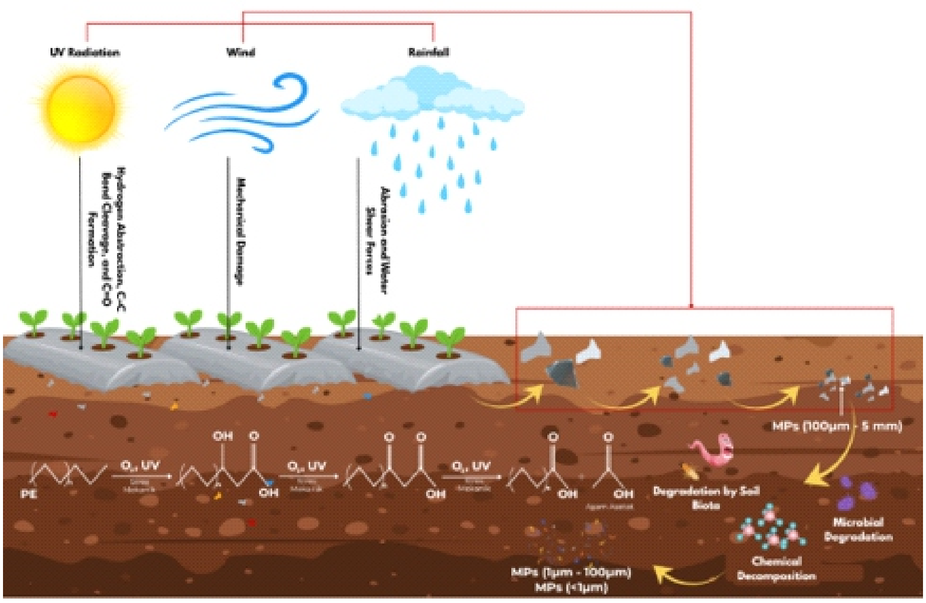
Source: Processed Primary Data, (2025)

Figure 3

Shape and Size Distribution of Microplastics

soil biota and microbes proceed. Smaller microplastics are more likely to enter soil pores, be carried by water, and ultimately interact directly with microorganisms. This aligns with the research by (Yu et al., 2021), found that small microplastics tend to migrate to deeper soil layers. This condition can affect the activity of soil biota because microplastic particles can disrupt the physiological functions of microorganisms and alter the physical and chemical properties of the soil. According to (Cahyaningrum & Sari, 2024), the extremely small size of microplastics allows these particles to enter and move through soil organisms, such as earthworms, either via their movement pathways, excretion processes, or by adhering to the worms' body surfaces. Chemical and biological degradation processes may further reduce particle size, resulting in microplastics <100 µm that are more resistant to degradation.

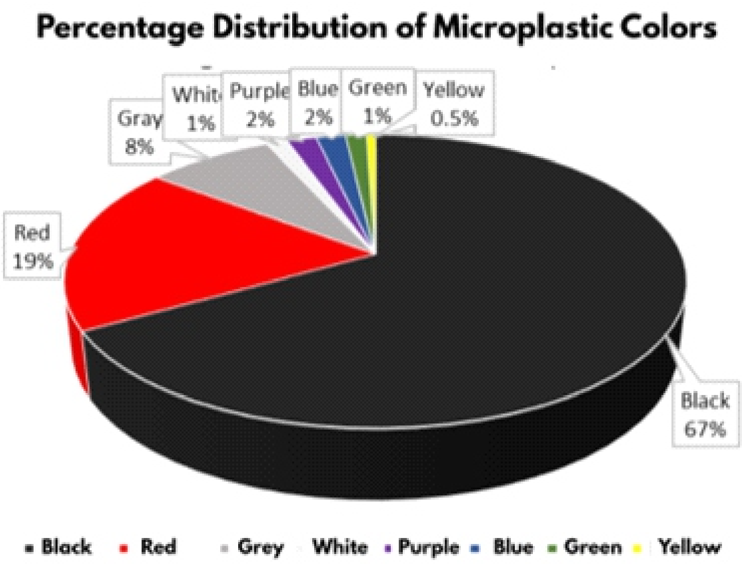
The data in Figure 5 show differences in color across various agricultural lands. Based on the graph, black microplastics are by far the most abundant, accounting for 67%, followed by red at 19%, and gray at



Source: Processed Primary Data, (2025)

Figure 4

Degradation Process of Plastic Mulch in Soil



Source: Processed Primary Data, (2025)

Figure 5

Percentage Distribution of Microplastic Colors

8%. Other colors, such as white, purple, blue, green, and yellow, were found in much smaller percentages ranging from 0.5–2%. The dominance of black is closely related to the use of dark-colored plastic mulch in agricultural fields that has degraded due to exposure to sunlight and field activities. Dark colored plastic degrades more quickly than light colored plastic because it absorbs more heat from sunlight, making it more prone to breaking down into microplastics (Wibisono, 2024). The color black also has a high capacity to adsorb pollutants, so it has the potential to carry various chemical contaminants and other particles that adhere to its surface (Ayuningtyas, 2024).

The color red ranked second and is believed to originate from other plastics used in agricultural activities, such as fertilizer packaging, pesticides, or red raffia twine that has degraded due to weather or human activity. The presence of red particles reflects the influence of human activity around the land, whether from farmers' activities or household plastic waste. Gray ranked third in abundance and may have originated from the original color of the mulch or from the weathering of dark colored plastics, such as black or dark blue materials, after physical degradation or oxidation caused by exposure to UV or infrared radiation. The color change to gray may also result from plastic mulch sheets that have been in use for a long time and have undergone mechanical or chemical degradation. Gray particles can indicate that microplastics have been present in the soil environment for a long time and have undergone further degradation (Taqia, 2024). The color variations observed in microplastics not only indicate the source of the plastic but also the extent of degradation occurring in agricultural environments.

Long term use of plastic mulch carries the risk of leaving plastic residues in the soil, even though plastic mulch offers significant benefits. As microplastics break down, they will be distributed both on the soil surface and within the soil layers over time. The accumulation of microplastics in the soil can damage soil structure, reduce porosity, and decrease water infiltration capacity; these conditions can change nutrient cycling and soil microbial composition, negatively impacting plant growth. Meanwhile, bioturbation activity can also transport microplastics to deeper soil layers, where they can clog soil pores (Sajjad et al., 2022). Plastic residues from mulch that degrade into microplastics in agricultural lands and urban areas will interact with heavy metals, pesticides, and persistent organic pollutants (POPs), thereby creating combined toxic effects on soil flora and fauna and being carried by runoff into rivers, lakes, and eventually the ocean, which can exacerbate environmental pollution (Anderson et al., 2017; Sighicelli et al., 2018; Yu et al., 2016; Zhang et al., 2017).

The use of plastic mulch has been shown to increase microplastic abundance in agricultural soil. This situation indicates the need for more environmentally friendly alternatives to maintain land productivity without adding to pollution. Organic mulches such as straw, rice husks, sawdust, or compost can serve as alternatives because they do not produce microplastics (Mansoor et al., 2022). Cover crops can also serve as an alternative to plastic mulch (Abbate et al., 2023). The use of biodegradable plastic mulches (BdPMs) made from soil-degradable polymers, such as starch-based polymers, polylactic acid (PLA), and polybutylene adipate terephthalate (PBAT), can help reduce the risk of long-term microplastic accumulation compared to conventional plastic mulch (Bandopadhyay et al., 2020).

CONCLUSION

Based on the results of the study, it can be concluded that fields using mulch have a higher abundance of microplastics compared to non-mulched fields. The primary source of microplastics in non-mulched land is limited to off-site residues. In contrast, in mulched land, microplastic contamination also originates from the mulch material itself. Generally, microplastics are more commonly found in the surface layer; however, the detection of microplastics at depths greater than 20 cm confirms the occurrence of vertical migration of microplastics into deeper soil layers. The results of the microplastic characterization analysis show that the microplastics found across all land uses consist of fibers, films, and fragments. Microplastic sizes are dominated by small (0.05–0.1 mm) to medium (0.2–0.3 mm) particles, with smaller particles having a greater potential to penetrate deeper soil layers. Black was the most common color of the microplastics, accounting for 67% of the total, consistent with the original color of the mulch and indicating a high amount of absorbed contaminants. Red accounted for 19%, and gray for 8%, indicating further weathering processes. Long-term use of plastic mulch may lead to microplastic accumulation and adversely affect soil quality. Sustainable alternatives include organic mulch, cover crops, and biodegradable mulch.

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