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MICROPLASTICS POLLUTION IN AGRICULTURE AND IMPACT OF MICROPLASTICS ON INSECT HEALTH AND AGROECOSYSTEM FUNCTIONING

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Abstract
Microplastics pollution has become an increasing environmental issue on the land ecology especially in the farmland soils where plastic products are extensively used to cultivate crops. Microplastics, which are plastic materials that are below 5 mm, are formed by the breakdown of large materials like mulch film, greenhouse covers, irrigation pipes, and packaging materials. Other sources involve sewage water application, wastewater irrigation, and compost amendment, that all add up to microplastics in agro ecosystems. The microplastics may stay long due to their resistance and persistence in soils and interact with different parts of the soil environment. Recent research indicates that microplastics can potentially influence the soil structure, porosity, water retention ability as well as the processes of nutrient cycling, which consequently have consequences on soil fertility and plant growth. Such particles also enter into contact with soil microorganisms and invertebrates and it is possible that they can change microbial powers and ecosystem activity. Agricultural systems may be exposed to microplastics by contaminated soil, food trophic transfer, plant tissues, or insects. This can have consequences on the physiology of insects, intestinal microorganisms, dietary habits, and reproductive fitness. Microplastics may also be exposed to the honeybees by means of contaminated pollen and nectar, which can be hazardous to the health of pollinators and services to crops. It also indicates the existing research gaps, and the need to implement sustainable plastic management and green agricultural practices to minimize the microplastics contamination of agroecosystems.

Introduction

Microplastics pollution has become a major environmental issue concerning the terrestrial ecosystems, specifically in agricultural sceneries whereby plastic substances are extensively utilized in crop cultivation and irrigation control. Micro plastics are that which are composed of plastic material of less than 5 mm and manufactured micro scale sized particles in industrial products. Agricultural operations also contribute micro plastics into soils by means of degradation of plastic mulches, irrigation pipes, greenhouse covers, and packaging materials of the farming systems (Das & Alam, 2024).

Plastics have become essential in modern agriculture since it increases crop production, saves water, and controls soil temperatures. Nevertheless, those materials that are helpful in crop productivity may pose environmental hazing when broken down into minute particles in the course of time. Such tiny microplastic can live decades in soil since most of the plastics are not biodegraded by microbes. Thus, they build up in the soils of the agriculture sector and interrelate with soil organisms, plants, and ecological processes (Suthar, 2025).

Studies in the last ten years have indicated that agroecosystems are potential source of micro plastics. It has been extensively investigated that soil environments have received little focus on the part of researchers researching on plastic pollution. It has been indicated that the agricultural soil can have even greater levels of micro plastics in fertilizers and irrigation water (Gorde *et al.*, 2024). Micro plastics has the capability of affecting various physical and biological activities within soils. Their occurrence can change the soil aggregation, water retention potential and microbial activities, which may have an impact on crop productivity, and ecosystem stability. Such effects do not limit themselves to the health of soil since insects and other invertebrates inhabiting agricultural areas might consume micro plastics directly or indirectly due to food contamination (Tayyab *et al.*, 2024).

The Insects have important roles in the agro-ecosystems because they render services, which include pollination, pest management, and degradation of organic matter. When micro plastics collect in soil, they may get access to the gut of insects and possibly disrupt nutrient uptake and physiology. The interaction poses crucial issues that concern the sustainability of the agricultural ecosystems and food security in the long-term (Zhu *et al.*, 2018). Ecological impacts of micro plastic pollution are not, therefore, confined to soil pollution. They are rather intricate interactions between plants and soil organisms, insects, and higher trophic cascades in terrestrial food webs. The research of these interactions is the key to assessing the environmental risks of using plastics in the agricultural sector and creating sustainable methods of its management (Rillig *et al.*, 2021).

These pollutants are able to stick on plastic particles surface and are carried by the soil and water systems. Consequently, micro plastics can serve as carriers of various contaminants, increasing their ecological effects in agriculture sector (Wang *et al.*, 2020). Growing popularity of plastics are used in agriculture all over the world evidences the urgent necessity to realize the sources, distribution, and ecological implications of microplastic pollution. Researchers are currently working on the health of soil, insect populations, and ecosystem service maintenance in agricultural productivity in response to micro plastics (Qi *et al.*, 2020).

Sources of Microplastics

Recently, agricultural soils were also identified as a valuable source of microplastics pollution. Soil microplastics are deposited by agriculture and waste products unlike in the marine systems where plastics are carried by water currents. Agroecosystems are also important sources of microplastics pollution through several farming activities which introduce plastic particles into the agricultural land unintentionally. The widespread application of plastic mulching films is one of the greatest sources as it breaks into smaller particles under the influence of ultraviolet radiation, mechanical forces, and the action of microorganisms (Tariq *et al.*, 2024).

Microplastics can be find out in contaminated water management of domestic and industrial source and accumulate in sludge in the course of treatment. The introduction of microplastics to soils may take place in bulk when sludge is spread on farms to enhance soil quality (Nizzetto *et al.*, 2016). Research has revealed that millions of microplastics particles per hectare can enter soils in a single year by only applying sludge. Other carriers of microplastics particles can be organic fertilizers like compost. Compost based on municipal solid waste usually includes plastic pieces, synthetic textile fibers, and remnants of packaging. The end product still contains small plastic parts after compost processing and is deposited on the agricultural soils during fertilization (Weithmann *et al.*, 2018).

Microplastics can also get their way into soils by use of agricultural irrigation systems. Plastic particles in rivers, reservoirs and wastewater that are used to irrigate fields are often a result of urban discharge and industrial effluent. In cases where the repetitive use of such water on fields entails embedding microplastics into soil layers, they can therefore react with soil organisms (Allen *et al.*, 2019).

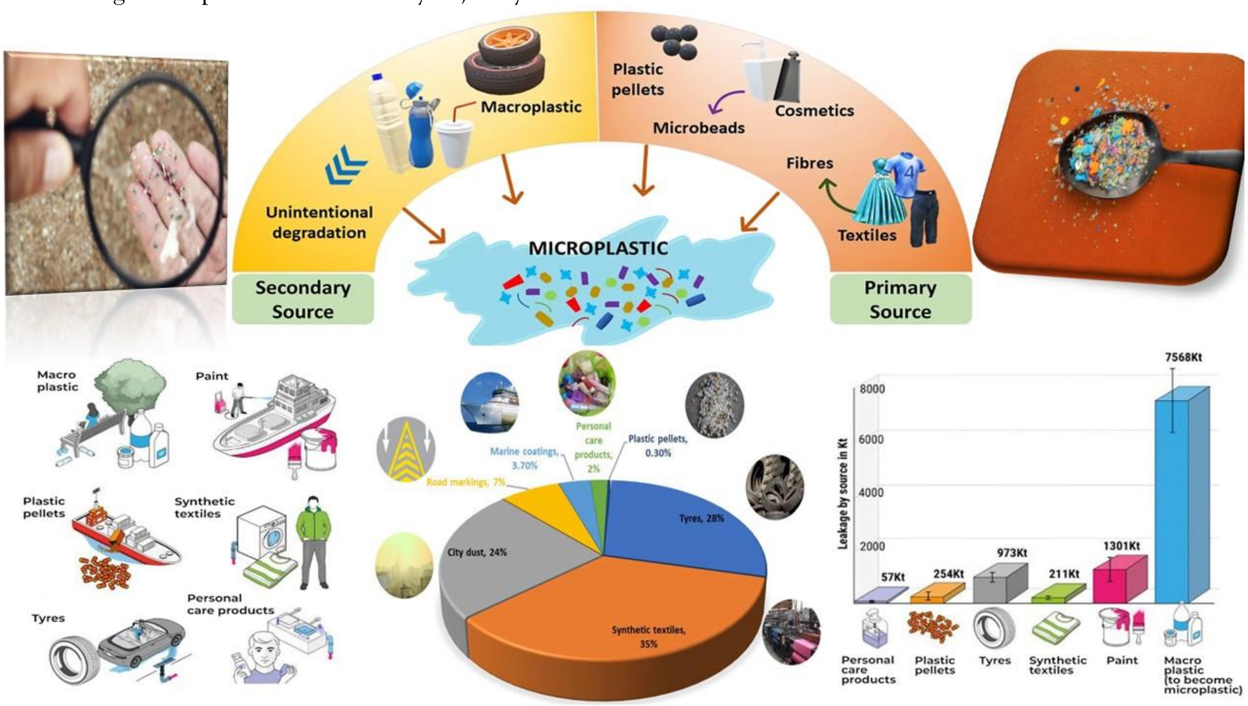

Figure 01. Primary and secondary sources of microplastics.

Atmospheric deposition is another source that has been ignored. According to recent studies, microplastics may spread a long distance in the atmosphere and eventually settle on the surface of the land. The urban setting and industrial areas produce plastic waste that could ultimately find its way onto the rural farms, and this contaminates the soil in remote agricultural systems (Brahney *et al.*, 2020). Plastic greenhouse blankets and irrigation pipes are other sources of microplastic pollution of soil. As time progresses, these materials will be eroded by sunlight and other environmental stressors to form pieces which enter the environment in which they are deposited. Incessant exposure of polymer chains to ultraviolet radiation increases the microscopic disintegration of polymer molecules (Steinmetz *et al.*, 2016). The packaging material of seeds, fertilizers, and pesticides can also cause plastic waste which finally degrades to microplastics. Poor management of these resources in the agricultural fields may cause slow breakage and integration into the soil structure (Bläsing and Amelung, 2018).

These are synthetic rubber particles of tires which are emitted when cars are on the road. They eventually get deposited in the soils of the roadsides and surrounding farmlands and serve as an extra source of plastic based pollutants (Kole *et al.*, 2017). The compounding of microplastics due to various sources has given way to the complexity of soil contamination within the agricultural ecosystems. All sources add differently to the farming practice, waste management systems of the region and environmental condition. Consequently, the distribution and concentration of microplastics may differ greatly among agricultural landscape (Sheng *et al.*, 2024). Policymakers and farmers can implement measures to reduce plastic consumption and enhance its management through identifying the pathways of contamination, which prevail in the majority of operations. This has to be done to safeguard the health of the soil, biodiversity, and sustainable production of agriculture in the future (FAO, 2021).

Formation of Microplastics from Agricultural Plastics

The process of microplastics development in agricultural soils is mainly caused by the breakdown of bigger parts of plastics utilized in the course of agriculture. Plastics are common agricultural covers like mulch films, greenhouse wraps, irrigation hosing, and packaging material that are used to enhance crop production and use of resources. Nevertheless, such plastics hardly degrade, but they break into smaller fragments in time (Guo & Wang, 2023). Photo degradation is one of the significant mechanisms that result in the formation of microplastics. The Sun produces ultraviolet radiations that are capable of splitting the chains of polymer in the plastic materials making them brittle and breaking into tiny pieces. It is especially typical of plastic mulching films used in the process of crop cultivation, which are continuously exposed to sunlight (Huang *et al.*, 2022).

In the agricultural fields, mechanical stress also contributes significantly towards plastic fragmentation. Plowing, harvesting and soil cultivation are the activities that can physically fragment plastic residues in smaller pieces. Regular farming activities enhance the process and cause microplastic to be formed in layers of soil (Zhou *et al.*, 2022). The environmental weathering and fluctuation in temperature also add to the decomposition of the agricultural plastics. Temperature fluctuations may result in the growth and shrinking of plastic substances, breaking them and making them prone to disintegration. During a certain period, these stresses on the environment convert large plastic waste into microplastic materials that become integrated into the soil. Microplastic is also formed due to chemical degradation. Polymer structures can be degraded by oxidation reactions which are initiated by exposure to oxygen, moisture and pollutants in the environment. These reactions slowly decrease diameter of plastics and transform them into microplastics that are hard to eliminate in soil systems (Dong et al., 2021).

Biological activities can determine the degradation of plastics in agricultural soils as well. Some microorganisms have been found to colonize on surface of plastic particles and help in their degradation by enzymatic activity. This process is slow, but it may at some point lead to breaking down of the plastics into very small sized particles (Yoshida et al., 2016). When plastics break down to small fragments, their surface area greatly expands. This property enables microplastics to become more active soil organic matter, microorganisms, and pollutants (Huerta-Lwanga *et al.*, 2017).

Minute size nanoparticles can invade the roots of plants and biological tissues in an easier manner in comparison to bigger plastic particles. It is noted that nanoplastics can threat to the environment in agricultural ecosystems (Gigault *et al.*, 2018). Microplastics in soils cannot disappear and their content could continuously grow over time. Plastics are very slow to decompose, and since agricultural products form the major part of the plastics, the pieces formed in the soil can take decades or even centuries to be broken down. This sustainability is of great concern about the sustainability of agricultural practices based on plastics. To come up with alternatives to the current agricultural plastics, it is necessary to understand the processes that promote the formation of microplastics. The biodegradable materials and better waste management solutions are also being considered by scientists to minimise the adverse effects of plastics (Sintim, Flury, 2017).

Types of Microplastics

The agricultural soils containing microplastics are categorized using a variety of features, which are size, form, the polymer type, and source. These categories are significant since various types effect organisms and ecological processes. To measure the effects of microplastics on nature, it is thus necessary to understand their types that exist in farmlands (Wright et al., 2013).

Microplastics are usually considered as any plastic pieces that are less than 5 millimeters in diameter, but other researchers further subdivide them into smaller groups like mesoplastics, microplastics and nanoplastics. Nanoplastics have a lot in common with the fact that they are able to enter the biological membrane and reside in living organisms (Andrady, 2011). The other significant categorization Is in accordance with shape and morphology. Agricultural soils may be contaminated with microplastics as mulch thread or pellets and foams. The shapes can be of different types and behave differently with soil particles and organisms (Barnes *et al*., 2009).

The polymer composition is also a division of microplastics. Polyethylene, polypropylene, polystyrene, are some of the common polymers found in agricultural soils. The chemical characteristics and degradation rates of these polymers can also have an effect on their persistence and ecological impacts on soils (Browne *et al.*, 2011). Small size microplastics are designed to be fabricated in microscopic dimensions with the aim of using them in other product types like cosmetics and industrial abrasives. Secondary microplastics are obtained as a result of breakdown of bigger plastic substances already existing in the environment (Carpenter & Smith, 1972).

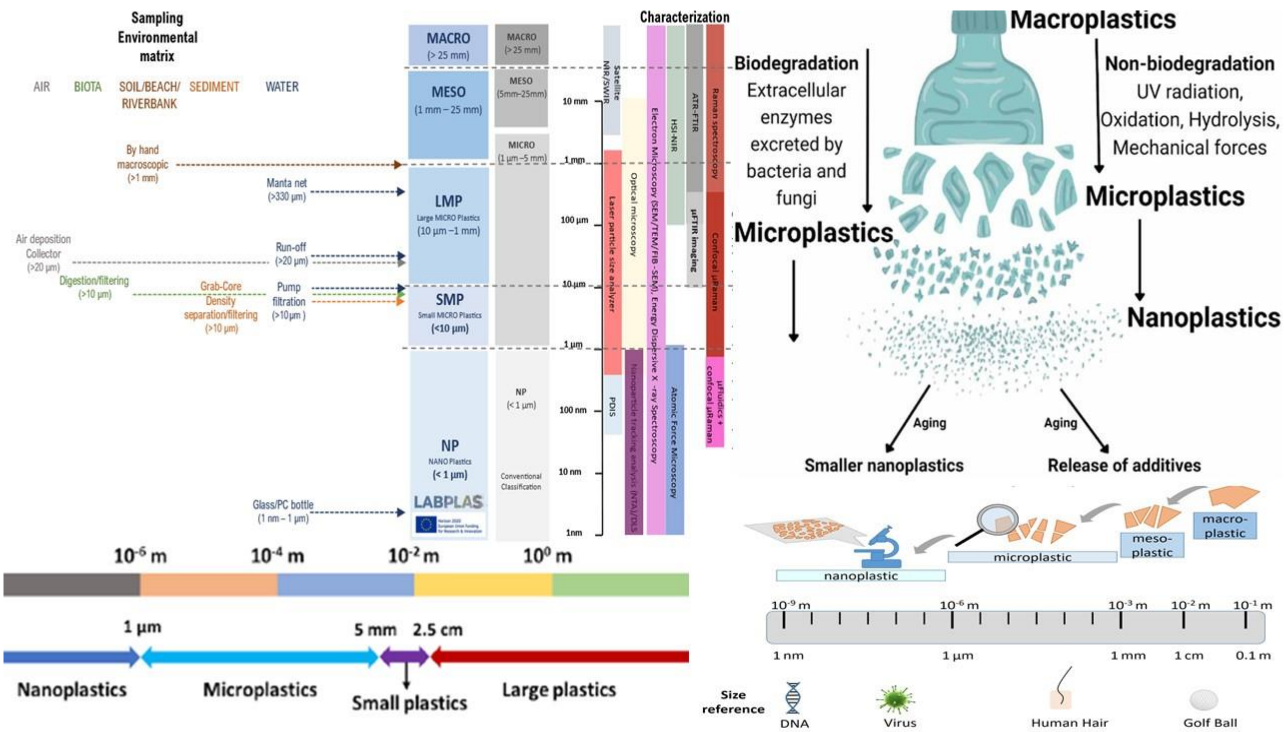

Figure 02. Types of microplastics causing pollution in agroecosystem.

The soils used in agriculture are mainly found to have second generation forms of microplastics that are a result of shredding plastic mulches, greenhouse covers and irrigation systems. Gradually, such materials disintegrate into fine particles, which accumulate in layers of soil and interact with community members (Qi *et al.,* 2018). Microplastics can differ in surface properties, which determine to absorb pollutants including heavy metals and pesticides. Rough particles have more chances in contamination than those of smooth particles which further increases the toxicity to the ecology (Cole *et al*., 2015).

The light weighted plastics can travel more readily through the soil pores and water flow channels than the heavy plastic materials (Corradini *et al.*, 2019). The complexity of the environmental issue is demonstrated by the variety of types of microplastic that are present in agricultural soils. The various particles can have different ecological impacts with reference to their physical and chemical characteristics. Thus, the investigators should take into account various categories when analyzing this issue in the farmland ecosystem (Cózar *et al*., 2014).

Pathways of Microplastics Entry into Agricultural Fields

The agricultural soils are subject to exposure to microplastics in various ways. These routes entail direct agricultural activities as well as indirect pathways of environmental transports which inject plastic components in the farmland ecosystems. The knowledge of such routes is fundamental to finding the best methods to mitigate contamination (Dris *et al.*, 2015). This is through application of plastic mulch films which are one of the most direct pathways and which are applied to enhance crop yield and soil moisture retention. With time, the material of these materials remains on the soil after harvest and breaks down to microplastics. The constant application of plastic mulching may in turn result in high amounts of harmful particles (Eerkes-Medrano *et al.*, 2015). The amount of contaminated microplastic particles can be huge in the irrigation water which is either acquired via rivers, lakes or treatment wastewater. Repeated use of this water on agricultural land leads to the fact that the plastic particles are incorporated into soil layers (Eriksen *et al.*, 2014).

The fertilizer of sewage sludge also contributes to the pollution of microplastic. Microplastics are trapped by wastewater treatment plants in filtration schemes, and the waste is stored in sludge. In the case of the sludge being thrown onto the farmlands, it is directly transported into soil ecosystems (Gall & Thompson, 2015). Another pathway that microplastics is emerging to enter agricultural settings is through atmospheric deposition. The plastic fibers and fragments may be carried by wind currents and ultimately, they may land on the land surfaces such as crop fields. Research has established that microplastics are transported to even remote agricultural areas via atmosphere (Brahney et al., 2020). Microplastics in the cities can also find their way into the farmlands due to flooding and surface run offs. Water can carry plastic particles that are in the road dust, industrial waste, and urban drainage systems to be deposited in the adjacent farmland (Horton *et al.*, 2017).

The other route is agricultural wastes and organic fertilizers. The municipal waste compost contains a lot of small plastic fragments that are not destroyed during compost formation. In the case of applying such compost to the soil, microplastics are brought to the agricultural ecosystem (Zhang and Liu, 2018). The indirect source of microplastics contamination can also be livestock farming. Animals can ingest the plastic particles found in their feed or water that can be transferred into the soil by way of manure. Microplastics increases its inflow into the agriculture soil through manure application (Galloway *et al.*, 2017). These particles settle in the soils of the roads and can be transferred in adjacent agricultural land by wind and water motion (Kole et al., 2017). The fact that there are several routes of access underscores the prevalence of microplastics pollution in farmlands. All the pathways play a role in gradual accumulation of plastic particles which interacts with soil organisms, insects and plants. These routes are utilized to decrease environmental risks posed by microplastics pollution (Hidalgo-Ruz *et al.*, 2012)

Global Distribution of Microplastics in Agricultural Soils

Agricultural sand in most areas of the earth have been cited to be contaminated with microplastic implying that plastic pollution does not occur exclusively in aquatic environments. In the last ten years, scientists have become more inclined to accept the fact that the soils of farmlands can have significant amounts of microplastics as a result of constant agricultural inputs and environmental transportation flows. The surveys in Europe, Asia, and North America have shown that the agricultural soils may have thousands of microplastics particles per kilogram of soil under local farming practices and plastic use intensity (Jambeck *et al.*, 2015). The minutes plastic particles contaminate soil in places where sludge is used can surpass the amount of microplastic that flows into the oceans on an annual basis (Koelmans *et al.*, 2015).

Studies done in China have shown that especially in intensive agricultural land, there is a high level of microplastics. Vegetable production systems that utilize plastic mulch films have also led to the occurrence of massive layers of plastic fragments into the soil. Research has also indicated the existence of a number of hundreds of kilograms of leftover plastic in the agricultural soils in some regions because of the repeated use of mulching (Kooi & Koelmans, 2019). The microplastics accumulation has also been observed in the European agricultural landscapes. German and Swiss studies identified microplastics in soils in both cases where organic fertilizers were used, which were made of municipal waste. These papers proved that amendments of compost and sludge can drastically raise the level of microplastics in the farmland soils (Law & Thompson, 2014).

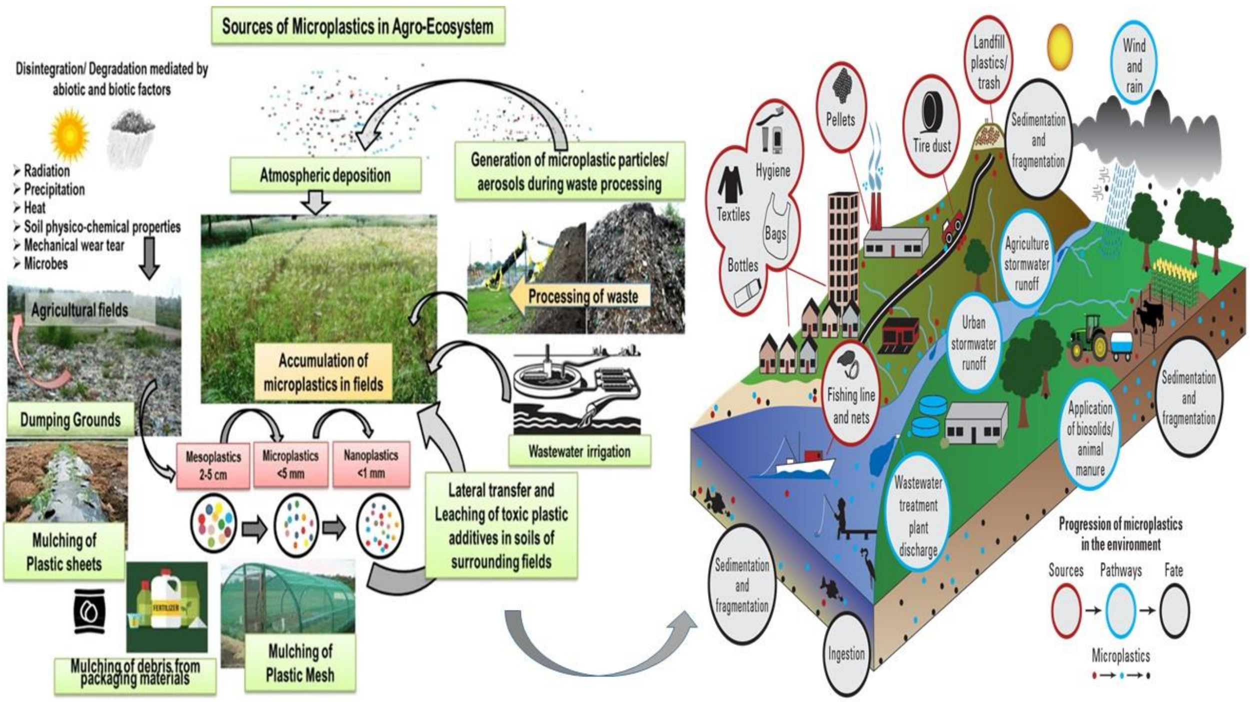

Figure 03. Several factors release microplastics that pollute agricultural land.

Microplastics pollution has also been found in the soils that were irrigated with treated wastewater in North America. The recurrent irrigation with the polluted water injects plastic particles that eventually build up in the soil profiles. With time, these particles can settle further into the layers of the soil by the movement of water and biology processes (Lebreton *et al.*, 2017). Microplastics are also spreading in the atmosphere as a result of transport. Plastic that is generated in an urban setting may take considerable distances before being deposited on land surfaces due to the wind currents. Consequently, even the distant areas of agriculture have been discovered to harbor traceable levels of the microplastic contamination (Lusher *et al.*, 2013).

Some of the factors which causes the spatial distribution of nanoparticles in agricultural soils are climatic, soil properties, and land management practices. Areas where agriculture has a high level of plastic use are likely to have a high level of microplastics concentration. Likewise, the regions where the organic waste fertilizers are used in high amounts can also be characterized by high contamination levels (Ma *et al.*, 2020). Soil texture and soil structure is another factor that influences distribution. Clays and fine-textured soils might also harbor microplastics better than sandy soils where the particles can be easily transported by the flow of water. These variations show the significance of soil features in the process of soil blockage and transportation of nanoparticles in agricultural areas (Boots et al., 2019). Although more research now exists, the distribution of microplastics in agricultural sand throughout the world has not been well quantified yet. Numerous parts of the globe especially the developing nations are not well monitored through studies. It is hard to determine the actual extent of terrestrial microplastic contamination because of this gap in knowledge (Rillig et al., 2021; FAO, 2021). Knowledge of global trends of microplastic pollution is paramount in designing international approaches to deal with plastic pollution in the agricultural sector. The monitoring programs and standard sampling techniques will be required to precisely determine this environmental problem and measure its ecological effects (Mintenig *et al*., 2017).

Role of Plastic Mulching in Microplastic Accumulation

Plastic mulching is one of the prevalent agricultural methods adopted because it enhances the productivity of crops and improves the soil. Plastic films are employed by farmers to cover the soil surfaces to preserve moisture, weeds, and manage soil temperature. Despite these advantages, plastic mulching is also related to the increase of nanoparticles in soils, despite the fact that such a solution has become popular in various areas (PlasticsEurope, 2021). Majority of agricultural mulch films consist of polyethylene which is an anti-degradable polymer. When the crops are growing, the films face the sun, wind, change of temperature, and mechanical loading. Gradually, such environmental circumstances weaken the plastic material and break it into smaller parts which are left in the soil after the film is taken away (Ryan *et al*., 2014).

Plastic mulch in most farming systems cannot be totally removed even after harvesting. Small pieces are usually left in the ground and later decayed into microplastics by the weathering process. However, it is possible that plastic particles can accumulate considerably in the agricultural soils with the repeated use of plastic mulching in several growing seasons (Seltenrich, 2015).

Research has been done with intensive vegetable production systems and has shown that long term plastic mulching may lead to large depositions of residual plastics in farm land. Certainly, samples of soil have also contained visible pieces of plastic and microscopic fragments formed by disintegration of older mulch films. These plastic residues have more environmental effects than just the contamination of soil. Microplastics of mulch films can come into contact with such organisms of the soil as earthworms, insects, and microorganisms. Such interactions may affect the biological processes in soils and may even disrupt the work of the ecosystem (Shahul Hamid *et al*., 2018).

The other issue is that microplastics formed out of the mulch films might also absorb pesticides and other agrochemicals found in the soil. These polluted particles may serve as vectors in the spread of toxic elements that may enhance their movement and bioavailability in the soil ecosystem. The given process can subject soil organisms to a set of combined chemical and physical stressors (Sun *et al*., 2019). To overcome these issues researchers have embarked on exploring biodegradable alternatives of traditional plastic mulch films. These substances are prepared to decompose easier in the environmental conditions and decrease plastic concentration in soils. Nevertheless, the products of their degradation, as well as their ecological effects, still need to be investigated (Sintim and Flury, 2017). Better management methods are also being considered as a way of reducing plastic wastes in farmlands. As an illustration, plastic that is remaining in the sand can be reduced by better collection and recycling of mulch films following harvest. These measures are necessary to curb the microplastic pollution of agricultural environments (Kyrikou and Briassoulis, 2007).

Wastewater Irrigation as a Source of Microplastics

Irrigation of wastewater has also been more prevalent in areas where there is a shortage of water. The wastewater (treated or untreated) serves as an alternative water source to irrigate crops since it harbors nutrients that could improve the fertility of the soil. Nonetheless, microplastics are often found in wastewater that can be either domestic, industrial, and urban sources of microplastics (Thompson *et al.*, 2009). In the process of wastewater treatment, the vast majority of particles of microplastics are eliminated in water, and they are deposited in sewage sludge. However, a considerable proportion of these particles are left in treated effluent and can be released to rivers or can be utilized in irrigation processes. Consequently, wastewater irrigation may cause the direct entry of microplastics into the agricultural land (Van Cauwenberghe *et al*., 2016).

The microplastic materials in wastewater are usually fibers of synthetic fabrics, pieces of plastic package wrappings, and microbeads of personal care products. Such particles are normally small and light meaning that they can move easily through water distribution systems. When the wastewater is sprayed on the farmland, these particles accumulate in the mud and are integrated into the soil mass (Dris *et al*., 2016). When the pollution of water is repeated, microplastics may gradually accumulate in the soils of agricultural fields. In the long run, these particles can have contact with soil organisms and modify soil physical properties (Van Sebille *et al.*, 2015).

Another source of microplastic contamination of the ground water system is the wastewater irrigation. Small particles may travel through the soil pores and enter deeper soil layers especially in the sandy soils which are highly permeable. This trend causes the fear of the possible pollution of drinking water resources (Wagner *et al*., 2014). The other environmental issue is that in wastewater, microplastics tend to contain other wastes, including heavy metals, pharmaceutical residues, as well as organic pollutants. When such particles get to the agricultural soils, they can bring several pollutants at once and can pose more ecological hazards to the soil organisms and crops (Wagner & Lambert, 2018). These creatures may consume plastic pieces during the ingestion of the soil organic matter or plant residues. The given ingestion can disrupt the digestive system and nutrient uptake, which may lead to the impact of insect health (Ju *et al*., 2019). The issue of microplastics in irrigation water is therefore critical to be monitored in the context of determining the environmental safety of wastewater reuse in agriculture. Better wastewater treatment methods can be used to limit the emission of microplastics to irrigation systems (Wright & Kelly, 2017).

Atmospheric Deposition of Microplastics on Cropland

Recently, atmospheric transport has been considered an essential route of the transport of microplastics over long distances. Plastic dust in cities, industrial effluents, and synthetic textile fiber may be carried into the air and move around in the air before depositing on the surface. The microplastic particles can be deposited in agricultural fields that are far away in urban centers, hence the source of atmospheric pollution (Brahney *et al*., 2020). The microplastics found in the atmosphere are usually light fiber or fragments which can be suspended over a long time. These particles may be carried over many hundreds or even thousands of kilometers by wind currents before they are deposited. That is why microplastics are observed even in mountainous and in the agricultural fields in remote areas (Dresden *et al*., 2018).

Isolated areas have indicated unexpectedly great amounts of microplastic deposition in the atmosphere. As an illustration, research conducted in mountainous areas in Europe had discovered that large amounts of plastic fibers were carried by rains and dry atmospheric fallout. Such results indicate that microplastic distribution on an international scale is significantly influenced by atmospheric transport (Zhang *et al.,* 2017). When microplastics are deposited to farmlands, they are likely to accumulate in the surfaces of soil and be incorporated into the deeper section of the soil by the biological and physical process. Their movement to soil can be achieved by earthworms, rainfall infiltration, and agriculture tillage (Rillig et al., 2017).

Manmade microplastics in the atmosphere are commonly found in the urban environment like the fibers of synthetic clothes that leak during washing. Plastic particles may be also added to the atmosphere by industrial activities and road traffic. The emissions ultimately may be deposited in the surrounding agricultural fields, contributing to the preexisting contamination with microplastic (Horton et al., 2017).

The ecological consequences of the atmospheric deposition are also pronounced since such a route leads to the introduction of microplastics in farmlands even in spaces where the use of plastics is minimal. Therefore, farmers can be subject to soil pollution even without the direct participation in the use of the plastic in farming activities (Rillig and Lehmann, 2020). Crops and insects in the agricultural ecology might also be exposed to atmosphere microplastics. Pollinators and herbivorous insects may come across plastic particles deposited on the surface of plants or a soil, which makes the ingestion more likely to occur. These processes demonstrate the complicated routes by which microplastics affect the terrestrial food webs (Zhu *et al.,* 2018).

Degradation of Agricultural Plastics into Micro and Nanoparticles

The agricultural plastics are made to be tough and hard enough to withstand environmental pressures, but they weaken and degrade at a slow rate when they are subjected to nature within the fields. This is a significant pollutant of microplastic development in soils since the plastic materials that are used in agriculture rarely decompose. (Rillig et al., 2017).

Photo degradation is one of the major processes that lead to degradation of agricultural plastics and in where the polymer chains of plastic death occur under the sunlight through the ultraviolet radiation. The constant exposure of plastics (polyethylene mulch films and green house covers) to sunlight compromises their structural integrity. Fragments of plastics are also caused by mechanical stress created in the course of agricultural activities. Plowing and harvesting as well as the cultivation of the soil used in farming puts pressure on the plastic residues that are left in the soil at the end of the harvest. These mechanical processes cause bigger pieces of plastic to be processed into small particles that slowly become microplastics (Boots et al., 2019).

Weathering of the environment also increases the rate of degradation. Changing weather conditions in terms of temperature, humidity, and soil moisture could degrade plastic materials with time. These conditions cause the physical constrains which facilitate the cracking and separation of plastics into microscopic sizes (de Souza Machado et al., 2018; Wang et al., 2020).

In soil environments, chemical oxidation is another way the plastics are degraded. Oxidative reactions that change the structures of polymers can be triggered by exposure to oxygen and reactive chemical compounds. Such reactions decrease the molecular weight of plastics and make them more vulnerable to fractures (Chae and An, 2018; Gigault et al., 2018). The more the plastics degrade into smaller particles the larger the surface area they cover. This has a greater surface area, which enables microplastics to be more active in contact with the soil components including organic matter, microorganisms, and pollutants. Therefore, smaller particles can possess more significant ecological effects than bigger pieces of plastic (Rillig and Lehmann, 2020; Wang et al., 2021).

Nanoplastics are the most worrying phenomenon to researchers who have been examining plastic pollution because they are formed by particles that are less than a micrometer in diameter. These decrease in size are very small and can easily enter biological membranes and can enter plant tissues or soil organisms more readily than the larger microplastics. Nanoplastics can thus have special ecological hazards in the agricultural ecosystems.

Table01. Impact of microplastics on insect health and agroecosystem functioning.

Microplastic Source in Agriculture	Type of Plastic Particle	Pathway into Soil / Agroecosystem	Impact on Insect Health	Impact on Agroecosystem Functioning	References
Plastic mulching films	Macroplastics → Microplastics	Fragmentation of polyethylene mulch films due	Soil insects ingest particles causing gut	Alters soil aggregation and reduces	Rillig, et. al., 2012

		to UV radiation and tillage	blockage and reduced feeding	soil fauna diversity	
Sewage sludge used as fertilizer	Microplastics & Nanoplastics	Wastewater sludge applied to farmland introduces plastic particles	Bioaccumulation in detritivorous insects such as springtails and larvae	Transfers plastics across soil food webs	Browne, et. al., 2011
Irrigation with contaminated water	Microplastics	Irrigation water from rivers or wastewater carries plastic fibers and fragments	Causes oxidative stress and physiological disturbance in insects	Pollutes rhizosphere affecting microbial–insect interactions	Rochman, et. al., 2013
Plastic greenhouse covers and tunnels	Macroplastics → Microplastics	Weathering and degradation release fragments into surrounding soil	Reduced growth rate and reproduction in insects	Alters pollinator and decomposer populations	Galloway, et. al., 2017
Polymer-coated fertilizers and seeds	Microplastics → Nanoplastics	Breakdown of polymer coatings in soil environment	Insects ingest particles while feeding on organic matter	Disrupts nutrient cycling and soil biological processes	Mintenig, et. al., 2017
Atmospheric deposition	Microplastics & Nanoplastics	Windborne synthetic fibers settle on agricultural land	Adhesion and ingestion by flying insects	Introduces plastics into terrestrial food chains	Allen, et. al., 2013
Agricultural plastic waste (bags, drip tubes)	Macroplastics → Microplastics	Mechanical breakdown due to tillage and environmental exposure	Toxic additives cause metabolic stress in insects	Reduces decomposition efficiency and soil fertility	Arias-Andres, et. Al., 2018

The degradation of the agricultural plastics may also be affected by microbial activities. Microbial degradation is usually slow, but it could also lead to the eventual disintegration of plastics into small sized particles (Yoshida et al., 2016; Urbanek et al., 2018). Of particular concern is the fact that these particles in soil environments remain long due to slow degradation of plastics as opposed to natural organic substances. Agricultural plastics create microplastics that can stay in soil decades later and build up over the years. Such long-term maintenance begs the question of the sustainability of agricultural practices that are intensive concerning plastics (Rillig et al., 2021; FAO, 2021).

To design measures that can help limit microplastic contamination, it is necessary to understand the processes of plastic degradation in agricultural soils. The current research now aims towards the creation of biodegradable alternatives and enhancing waste management to limit the presence of plastics in the farmland environment (Sintim and Flury, 2017; Kyrikou and Briassoulis, 2007).

Effects of Nanoparticles

The structure of the land is an important factor in defining the physical characteristics of the agricultural soils and their capacity to support the growth of plants. Microplastics may have an effect on the soil aggregation, pore development, and the stability of soil. The changes can impact the water flow, root growth, and nutrient supply in agricultural ecosystems. Microplastics may modify the soil fabrication by disrupting the natural process of soil particle aggregation. The aggregates of soil are created by the interactions of minerals, organic matter and microbial activity. In case microplastic particles exist on soil, they can alter these relationships and change the stability of the soil particles (Lackner & Besharati, 2025).

Some categories of plastics, especially fibers and films, may physically entrap the soil particles and alter the structure of land aggregates. The entanglement could make the soil more stable or more unstable, which is determined by the nature and amount of plastic particles. Consequently, the general composition of soil can be turned into more heterogeneous and less predictable (Huerta Lwanga & Santos-Echeandía, 2021). Microplastics may also affect soil porosity which is described as a pore space in soil that allows air and water to travel. The alteration of pore structure can influence the aeration and the process of water infiltration required in the growth of plants. In other instances, the microplastic can actually form more pore spaces enhancing soil permeability (de Souza Machado et al., 2018).

Nevertheless, a large amount of microplastics could negatively influence the physical characteristics of soil. Massive amounts of plastic debris can obstruct the soil pores and slow down water flow within the soil profile. Such decrease in permeability could cause bad drainage and less aeration in the soil (Jambeck et al., 2015).

Impact of microplastics on the soil structure can also be affected by the type of soils and environment conditions. The response of sandy soils to plastic pollution might be not the same as that of clay based soils due to the variation in the particle size and aggregation processes. These differences bring to the fore the complexity of the interactions of microplastic in the soil systems (Brown & Thompson, 2021). Earthworms, microorganisms, other soil organisms are important in the preservation of soil structure due to their biological activity. Microplastics can affect the behavior and survival of these organisms indirectly, which has an effect on the soil aggregation process. Alterations in biological functionality may then enhance the physical impacts of microplastic pollution (Fahrenfeld et al., 2019). The other possible effect of the microplastic contamination is a change in the root development of plants. Roots penetrate the soil using pores in the soil which give access to water and nutrients.

Since the agricultural productivity largely depends on the land structure, it is important to study the effects of microplastics concerning the soil structure determining the long-term sustainability of agricultural soils. It is also required to define the extent to which the accumulation of microplastic will eventually reduce the quality of soil or lead to the establishment of new structural opportunities in soils (Gigault et al., 2018).

Influence of Microplastics on Soil Water Retention

Water retention is a very important soil characteristic which dictates the capacity of soil to store and release water to vegetation. It also affects the retention of water in soil by changing the porosity of soils, aggregation of soils, and water movement routes. The implications of such changes could be significant to the crop growth and agricultural productivity (de Souza Machado et al., 2018; Wang et al., 2020). Micro plastics can alter the spread of soil pores which directly impacts the movement and storage of water in the soil matrix. The fibrous microplastics such as fibrous plastic can also enhance the porosity of the soil by providing more space of pore. Such porosity can boost its water infiltration and drainage in some soil types (Boots et al., 2019; Rillig and Lehmann, 2020). The effect of nanoplastics on water retention is not the same, however. Fragment-shaped particles resembling film might block the pores in the soil and slow down the flow of water in the soil. The latter can cause the localized retention of water or imbalance in the distribution of moisture in farm land (Wang et al., 2021).

Hydrophobicity of most plastic polymers can also impact on the dynamics of soil water. Chemical properties of plastics, which cause repulsion of water in most instances causes' inability of the soil to retain water in those areas where the plastic particles are concentrated. Such a hydrophobic property can form microorganisms in the soil, which has the effect of influencing water uptake by root of plants (Wang et al., 2020). The alteration of the soil water retention can also have an impact on the activity of the microbes and recycling of the nutrients. Microorganisms of soil require water to undertake their metabolic activities and changes in water supply can change the composition of the microbial community. In this way, microplastics can affect biological processes in soil indirectly by altering the processes of working with water (Boots et al., 2019).

Microplastic pollution can also pose additional problems to water management strategies in agricultural systems that require irrigation. The changes in the soil moisture may influence the irrigation efficiency and demand of crops. These effects show that microplastic pollution should be considered as an integral part when analyzing the soil water management practices (Rillig and Lehmann, 2020; Wang et al., 2021). Microplastic can also affect the growth of plants by altering the water retention of soil. It is known that crops depend on the level of soil moisture in order to develop physiologically. Under specific conditions, the stress of plants and low yields can be experienced when microplastics interfere with the water infiltration and retention balance (de Souza Machado et al., 2019).

A further key factor is how microplastics come into contact and soil organic matter. The organic matter plays a role in the enhanced water retention in the soil by increasing the aggregation and stability of soil pore. Microplastics can disrupt such processes and change the correlation of organic matter and soil moisture (Fahrenfeld et al., 2019). Whereas the current studies on this matter are still in the early developmental phase, the available literature has shown that microplastics can influence the soil hydrological processes both positively and negatively. The extent and orientation of these effects are affected by the type of plastic, particle size, concentration, and soil attributes (FAO, 2021).

The soil nutrient cycling is an essential ecological process which controls the supply of the necessary nutrients needed in the growth of plants and in the metabolism of microbes. The introduction of microplastics into agricultural soils has an opportunity to affect these processes by changing physical properties and biological interactions of soils (Lehmann, 2020).

The possible impact of microplastics is that they alter the soil aeration and moisture levels. It is possible that alterations in soil structure and pore distribution can impact on the availability of oxygen and water movement in the soil profile. These modifications have the ability to influence microbial metabolism which governs the process of transforming nutrients like the mineralization of nitrogen and nitrification (Wang et al., 2020). They have the ability to affect the nutrient cycling by changing the chemistry of microbial communities. Microorganisms in soil are also essential in the breakdown of organic substances and the transformation of the nutrients into plant absorbable forms. In case plastic particles have an impact on the microbial diversity or activity, the speed of nutrient conversion in soil can alter dramatically (Zhu et al., 2018).

These particles being able to adsorb nutrients on the surfaces of the material because of the high surface area and chemical properties. Nitrogen compounds or phosphorus are some of the nutrients that may be deposited on plastic particles and this can change their availability in the soil systems. Such adsorption may affect the movement and distribution of nutrients in farm soils (Hodson et al., 2017). The microplastics and the microorganisms associated with soil may also have impacts on organic residue decomposition as crop residues and manure. The decomposition of organic material might be slowed down in case there is a decrease in microbial activity caused by plastic contamination. This deceleration may decrease the emission of vital elements that support the growth of plants (Boots et al., 2019).

The microplastics can affect nutrient cycles too because they interact with the soil enzymes. Microorganisms produce soil enzymes that are significant in nutrient transformation like decomposition of carbon and recycling of nitrogen. The studies indicate that microplastics can either activate or repress the activity of enzymes, which is determined by their concentration and chemical characteristics (Wang et al., 2020; Rillig et al., 2021). The other effect that can be realized is the change of microbial hotspots in soil aggregates. These hotspots refer to the locations of high levels of microbial activity where the cycling of nutrients takes place very fast. This could be the case because nanoplastics in soil aggregates can change these micro environs and alter nutrient turnover rates (Rillig and Lehmann, 2020; Wang et al., 2021).

The gradual changes in nutrients availability in the agricultural soils could therefore be the result of the long-term building up of microplastics. Crop productivity and the functioning of the ecosystem can be influenced by even minor interruptions in the processes of nutrient cycling. This option also brings up the question of the sustainability of intensive agricultural activities based on plastics (FAO, 2021; Rillig et al., 2021). Even though the studies of this topic are still in their early stage, there is some evidence which indicates that the microplastics are capable of affecting the nutrient cycling either directly or indirectly. Direct impacts include the responses to the nutrients and soil enzymes, and indirect impacts are caused by the alterations in the microorganisms and soil texture (Villarrubia-Gómez et al., 2018).

The soil organic nutrients are a very important factor in ensuring soil is fertile and stable in the ecological system of agriculture. It helps for supply of nutrients, formation of the soil structure, and the ability to retain water. The emergence of microplastics in the soils can affect the relationships between the organic matter and the rest of the sand (Machado et al., 2018). Physical interaction with organic matter Microplastics can be physically interacted with organic matter by being trapped in aggregates of land that contains decomposing vegetable residues and microbial biomass. These processes have the potential to effect on the stability and development of soil aggregates. Consequently, the process of organic matter distribution and decomposition can also shift in the soils that are polluted with microplastics (Sunitha et al., 2021).

The other significant fact is that microplastics may serve as microbial colonization surfaces. The microorganisms of the soil tend to settle on the solid particles and form biofilms in which they execute metabolic activities. Microplastic particles can also offer more surfaces on which microbes can grow and this might affect microbial activity and organic matter decomposition (Corradini et al., 2019). The capacity of the nanoplastics to adsorb organic matter is also significant. Plastic particles have the capacity to attach organic molecules and humic substances in soil. This binding can have an impact on the movement and bioavailability of organic compounds which are significant to soil fertility (Hodson et al., 2017).

These plastics affect sand decomposition rate of organic matter. In case plastic particles can disrupt the ability of microbes to access organic materials, the rates of breakdown can slow down. The slowed release of nutrients needed to grow plants may take place through reduced decomposition (Boots et al., 2019). Other impacts of microplastics on sand include the stabilization of carbon in soil. The organic matter in the soil is a significant source of methane and the dynamics of its degradation may have an impact on the processes of carbon sequestration. Microplastics could have an indirect effect on global carbon cycling by altering the balance of organic carbon in sand aggregates in case these microplastics change its stability (Rillig et al., 2020).

In farm production where organic fertilizers like compost and manure are commonly used then the contact between microplastics and organic materials becomes even more topical. Organic fertilizers could include small pieces of plastic that get absorbed in the pools of soil organic matter. It can possibly lead to the build-up of plastics in the soil ecologies over time (Weithmann et al., 2018; Zhang and Liu, 2018). The mechanisms between microplastics and soil organic matter are critical to the assessment of their ecological effects in the long-term. These interactions have a role in influencing nutrient cycling, microbial activity, and soil structure, which are all important in the agricultural productivity (Wang et al., 2021; FAO, 2021).

Chemical composition and pH of the soil are also significant issues that determine the nutrient levels, microbial activities, and vegetative growth. Such particles in the land can alter how chemical substances spread and move (Hodson et al., 2017; Wang et al., 2021). Micro plastics can also influence microbial activity and therefore indirectly influence the pH of the soil. The microorganisms in the soil generate organic acids and other metabolites that control the acidity of the soil. In case microplastic contamination affects the microbial community structure, it could modify the synthesis of these chemical products and, thus, alter the soil pH (Boots et al., 2019; Zhu et al., 2018).

Degradation might cause the release of chemical additives into the soil when specific plastic materials are degraded. Stabilizers, plasticizers and colorants are some of the materials that are added in the manufacturing of plastics. Since plastics are biodegradable, these additives can seep into the soil and influence its chemical composition (Chae and An, 2018; Wang et al., 2020). The other significant issue that should be addressed is the contact of microplastics and agrochemicals that are applied in agriculture. Plastic particles can adsorb pesticides and fertilizers they contain in soil which can change their transport and persistence. Such a relationship can affect the performance of agricultural chemicals and their environmental effects (Hodson et al., 2017; Wang et al., 2021). Microplastics can also have an effect on ion exchange in soil. Nutrients are usually bound by soil minerals and organic substances via electrochemical reaction. Plastic particles can disrupt these mechanisms and disrupt the availability of nutrients to plants (Rillig et al., 2017; de Souza Machado et al., 2018).

Alterations in soil chemical characteristics may be significant to the health of plants and their productivity. In case microplastics modify the chemistry of soil, these changes have a potential impact on nutrient consumption by crops (Silva et al., 2018). The other potential impact is the change in buffering ability of soil which assists in the stabilization of PH in agricultural soils. The use of old plastic products can also lead to the degradation in the buffering capacity of the soil to changes in chemicals. This loss might make soil ecosystems more sensitive to the environmental disturbances (Xiong et al., 2024). There is some evidence that indicates that the microplastics have the potential of altering a number of factors in the soil chemistry. The effects can happen via adsorption mechanisms, additive release, and reactions with soil microorganisms (Chae and An, 2018). This knowledge of the effects will be crucial in formulating management practices that ensure the quality of the soil and agricultural output (Rillig and Lehmann, 2020).

The microbial communities in soils are key to the sustainability of soil and ecosystem processes and recent studies indicated that the occurrence of microplastic contamination may dramatically change the composition of microbial communities. The sources of microplastics in the agricultural soils include degraded plastic mulch films, wastewater irrigation, and an atmospheric distribution, which accumulate in soil environments in the long term (Rillig et al., 2019; Zhang et al., 2020). When introduced to soil, microplastic particles may affects the diversity and metabolic activity of microorganisms (de Souza Machado et al., 2018; Wang et al., 2021). Investigations have demonstrated that microscopic plastic fragments have the potential to alter bacterial populations, in particular, nitrogen-fixing bacteria such as Rhizobium, which play a key role in the nutrient recycling in plants (Huang et al., 2019; Fei et al., 2020).

Microplastics also serve as microbial colonization surfaces, also known as the plastisphere, when peculiar microbial communities form on plastic particles (Zettler et al., 2013; Jacquin et al., 2019). These communities could be very different to those occurring in the adjacent soils, and they might affect microbial interactions and nutrient transformations (Rillig and Lehmann, 2020; Zhou et al., 2021). Moreover, microplastics can influence the enzyme activities in ground that control the process of nutrient cycling like carbon mineralization, and nitrogen transformation (Qi et al., 2020; Zhang *et al.*, 2021). The alterations in the microbial community might decrease soil fertility and influence crop productivity in the long term (de Souza Machado et al., 2019; Wang et al., 2020).

The microbial biomass and microbial respiration have been found to be reduced in soils that are massively contaminated with polyethylene microplastics (Qi *et al.*, 2020; Zhou et al., 2021). The second Issue is that microplastics could help microorganisms move horizontally, as well as transfer genes carrying antibiotic resistance (Jacquier *et al.*, 2019). This procedure may have extensive ecological impacts on agricultural sustainability and soil ecology. All in all, it can be stated that the existing evidence suggests that microplastics can alter the composition of microbial communities, disrupt nutrient interactions, and may even pose a threat to the health of the soil in agroecosystems (Fei *et al.*, 2020).

Earthworms and other soil invertebrates are very important in preserving the soil structure, decomposition of organic matters and cycling of nutrients in agricultural ecosystems. Nevertheless, there is growing evidence that contamination with microplastic can be harmful to these organisms. *Lumbricus terrestris* are especially susceptible since they consume high amounts of soil when they are fed. In case of the availability of microplastics in soil, organisms may ingest them in combination with organic matter, which may accumulate in the digestive system (Rodriguez-Seijo *et al.*, 2017).

Experimental researches have established that ingestion of microplastic can decrease the growth rates and reproduction in earthworms. In the laboratory experiments, polyethylene particles led to a high weight loss and a reduction in the survival rates of earthworms in comparison with control groups (Wang *et al.*, 2019). These effects can probably be explained by the physical obstruction of the digestive tract and a decrease in the absorption of nutrients (Rillig *et al.*, 2019).

Microplastics also could influence invertebrates of soil by changing soil aeration and structure. Fibrous microplastics have the capability to transform soil aggregation and pore size and spaces, which shape earthworm and other soil fauna movement and burrowing (de Souza Machado et al., 2018; Qi et al., 2020). Besides earthworms other soil dwelling invertebrates like springtails and nematodes as well can be exposed to microplastic. To illustrate, the reproduction rate and feeding habits of *Folsomia candida* exposed to microplastic have been shown to be reduced and changed (Ju et al., 2019; Kim and An, 2019).

Mycorrhizal fungi, such as fungi in the soil, are all important constituents of the agricultural ecosystem as they increase nutrient absorption, soil structure, and growth of plants. Recently, microplastic pollution has become an aspect that is capable of changing the fungus communities in the soil. Microplastics are capable of altering the physical properties of soil like porosity, water retention, and aggregation, which can determine fungi growth and distribution (de Souza Machado et al., 2018; Rillig and Lehmann, 2020). These modifications do have the potential to have a negative impact on beneficial fungi like *Glomus intraradices*, which set up symbiotic interactions with plant roots (Lehmann et al., 2020; Zhang et al., 2021).

It has been shown that the availability of microplastics can lower the colonization of mycorrhizal in crop plants. Phosphorus and nitrogen can be transferred through the exchange of nutrients between plants and fungi, which can be reduced by limited colonization (Lehmann et al., 2020; Wang et al., 2020). This could be caused by physical obstacles formed by plastic particles around root surfaces (de Souza Machado et al., 2018; Qi et al., 2020).

Microplastics could also have an effect on fungal diversity, whereby new surfaces are formed on which microbial colonization can occur. There are fungi which can directly grow on the plastic particles and even contribute to degrading some types of polymers (Jacquin et al., 2019; Zhang et al., 2021). Nevertheless, this colonization can change the abundance of fungal communities to species that can withstand plastic contaminants instead of those which enhance plant growth (Rillig et al., 2019; Lehmann et al., 2020). The other possible effect is the interaction of tiny plastic particles with enzymes in the land that are generated by fungi. Plastic contamination may inhibit or alter enzymatic processes that are involved in the decomposition of organic matter (Qi et al., 2020; Wang et al., 2021).

Role of Microplastics in Transporting Soil Pathogens

Microplastics are also widely becoming known as vectors of microorganisms including potentially pathogenic organisms in soil ecosystems.

Microbial attachment can occur by having plastic particles that offer stable surfaces on which bacteria and fungi can proliferate to create biofilms (Carvalho et al., 2025). Such biofilms might harbor species of pathogens that can be conveyed throughout the soil through water displacement or agricultural activities or through soil organisms (Mintenig et al., 2017).

Microplastics can promote the distribution of plant pathogens including *Pseudomonas syringae* in soils of agricultural origin. Living organisms can also resist adverse environmental factors as pathogens that are attached to plastic surfaces could survive longer than those in free-living environments due to environmental protection offered by plastic surfaces (Zhou et al., 2021; Huang et al., 2019). Microplastics have the ability to deliver fungal pathogens that cause plant diseases. These agents are able to settle on the plastic and spread to the fields with the help of irrigation water or soil erosion (Jacquin et al., 2019).

One more issue is that microplastics can transport antibiotic resistant bacteria. Research conducted has revealed that plastic surfaces have the potential to carry genes that are related to antibiotic resistance and thus, transmit between microbial populations in soil ecosystems (Zettler et al., 2013). These processes may have both health and productive implications to the environment as well as agriculture. Altogether, the fact that microplastics can serve as vectors of pathogens indicates an emerging threat in the natural environment. Microplastics could facilitate the transmission and propagation of plant diseases, as well as cause disturbance to agricultural systems by facilitating the movement and survival of harmful microorganisms (Bhuyan, 2022).

Pathways of Microplastic

Microplastics may find their way into agricultural ecosystems by several exposure routes by insects that inhabit the environment. Such routes are consumption of contaminated food sources, exposure to plastic particles in soil, and indirect exposure via plant tissues (Huerta Lwanga et al., 2017). The insects that feed on the plant material or the soil organic matter are especially exposed to the risk as the microplastics build up in the soil and on the surfaces of the plants. When eating polluted roots or leaves, herbivorous insects have a risk of consuming microplastics. Studies have proved that microplastic particles may get absorbed by plant tissues and passed on to herbivores like *Locusta migratoria* (Arias-Andres et al., 2018).

Insects that live in the soil may also consume microplastics when they are feeding on detritus or on organic matter. Soil particles are frequently ingested by beetle and fly larvae during the feeding process, thus promoting the risk of microplastic intake (Khant & Kim, 2022). When consumed, these particles can build up in the digestive system and have an impact on the physiology of insects. Another animal group that is exposed to microplastics is pollinators by contaminated pollen and nectar. The deposited plastic particles may stick to pollen grains and be carried to the plants by the pollinating insects (Kappler et al., 2016).

Pollinators have role in agricultural systems since they ensure that most crops and wild vegetation reproduce. According to the recent research, pollinating insects are becoming more vulnerable to microplastic pollution by picking up pollen, nectar, and dust in the environment (Rillig et al., 2019; Zhang et al., 2020). The microplastic items have been found to be present on flowers as fibers of plastic in the air fall and combine with the grains of pollen. They can unintentionally consume the particles during pollination to the flowers, together with nectar or pollen (Lwanga *et al*., 2017). *Apis mellifera* (also known as the honey bee) is one of the pollinator species that has been thoroughly studied and found to harbor microplastic fibers on its body and digestive tract. It is observed in the field that microplastics can be trapped in loads of pollen that foraging bees collect (Al Naggar *et al.,* 2021).

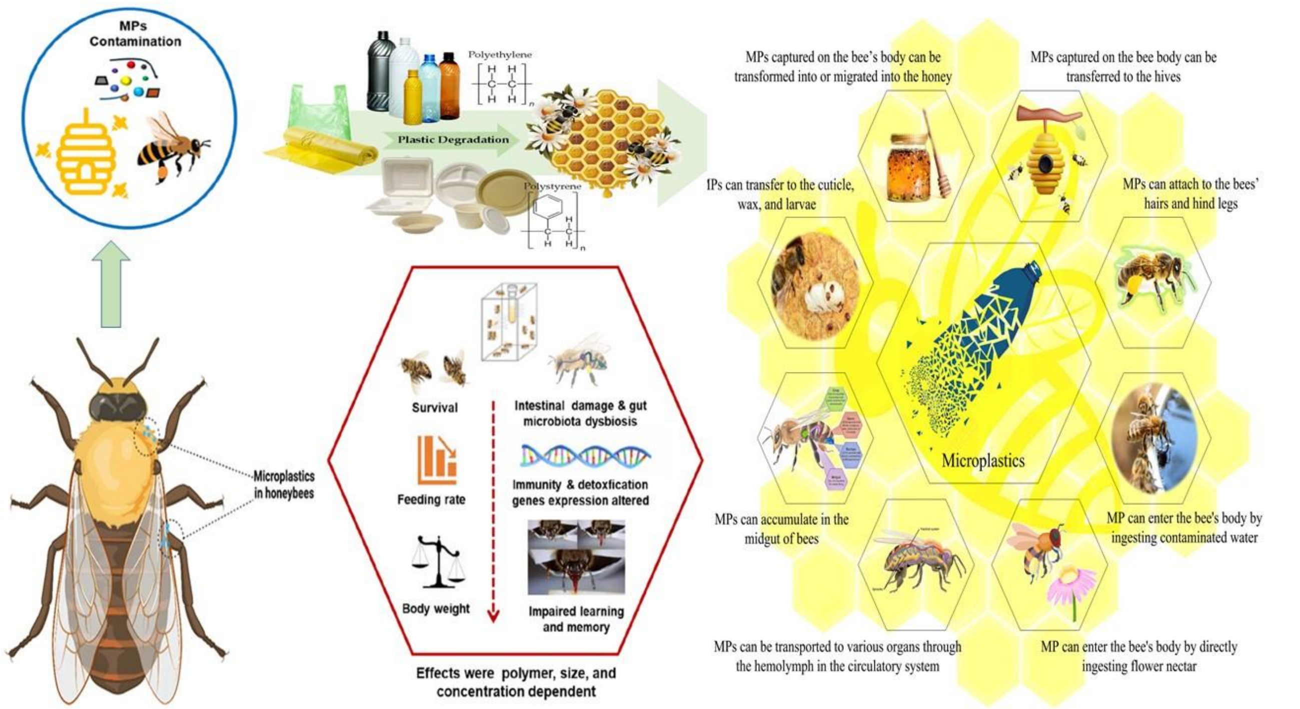

Figure 04. MPs causing hazardous effects to honeybees by contamination in different organs.

Another way microplastics can disrupt the nutritional value of the pollen eaten by pollinators is by disrupting its quality. Insects can end up getting less vital nutrition they need to survive and reproduce when some components of the pollen are substituted by pieces of plastic in their diets (Wang *et al.*, 2021). Nutrient-lowered nutrition may decrease the health of pollinators in the long run. Moreover, microplastics can be the carriers of toxic substances like pesticides and heavy metals which stick on their surfaces. The ingestion of such polluted particles by pollinators can subject them to further stresses of toxic substances other than the physical presence of plastics (Rillig et al., 2019; Zhou et al., 2021).

Honeybee digestive system is an important part in the absorption of nutrients and defense against diseases. Consumption of microplastic could alter the finely-tuned microorganism connection in the gut of *Apis mellifera*, which is crucial in keeping bees healthy (Al Naggar et al., 2021; Wang et al., 2021). Honeybees have an intricate population of gut microbes that aid in the digestion process, detoxification and guard against pathogens. Recent experimental evidence indicates that exposure to microplastics can change the Honeybee gut microbiome composition. Alteration in microbial diversity can decrease nutrient digestion and predispose microbes to disease (Al Naggar *et al.,* 2021; Rillig *et al.,* 2019). Plastic particles that are taken in may also result into physical irritation of the digestive tract. The other possible impact is the leakage of plastic additives and consumed pollutants. They can interfere with the metabolic activities of intestinal microorganisms and impair the immune system of bees (Wang et al., 2021; Zhang *et al*., 2020). In the long run, long-term exposure to microplastics might cause lower health and productivity of colonies.

Scientists have found that the consumption of microplastic can also cause a rise in oxidative stress in honeybees. Oxidative stress takes place when reactive oxygen species become harmful and are concentrated in the body, destroying cells and tissues. This kind of physiological stress may shorten the life-span and the reproductive ability of bees. (Al Naggar *et al*., 2021; Zhou *et al.,* 2021).

Microplastic Toxicity in Useful Insects

Much needed services to the ecosystem like predators and parasitoids ensure the regulation of agricultural pests? Nevertheless, these insects can also be contaminated with microplastic by surrounding it and food precursors (Zhang et al., 2020; Wang et al., 2021). As an illustration, the predatory insects can consume microplastics by feeding on the herbivorous insects that have already stored plastic particles in their organisms. This food web translocation amplifies the chances of microplastics to travel up the food chain (Huerta Lwanga et al., 2017; Zhou et al., 2021). Positively acting predators like *Coccinella septempunctata* might thus be exposed to unclean prey. Physiological stress in the beneficial insects could be caused by exposure to microplastics. There are laboratory findings that the consumption of plastic particles may lead to the decreased feeding performance, and energy stock (Ju et al., 2019; Kim and An, 2019).

Moreover, microplastics can bring chemical pollutants to the bodies of insects. Plastic particles frequently contain traces of pesticides and heavy metals that may be stored in the insect tissues (Rillig et al., 2019; Wang et al., 2021). These pollutants can interfere with the metabolism and decrease the survival rates. When the beneficial insects are reduced by exposure to microplastic, there is a possibility that the population of pests will rise in the agricultural systems. Those ecological inequities may result in increased dependence on chemical pesticides (Zhang et al., 2020; Zhou et al., 2021).

Exposure to microplastic may disrupt normal larval insect growth and development. A big number of insects feed extensively on their larval stage, thus risking the exposure to contaminated particles (Huerta Lwanga et al., 2017; Wang et al., 2021). When consumed, plastics can build up in the gastrointestinal system and block nutrient uptake. An experimental study in beetle larvae like *Tenebrio molitor* evidence has revealed that microplastic consumption may reduce the growth rates of a larvae. It can lead to reduced growth as plastic particles take over the space in the digestive system and do not fulfill the nutritional value (Ju et al., 2019).

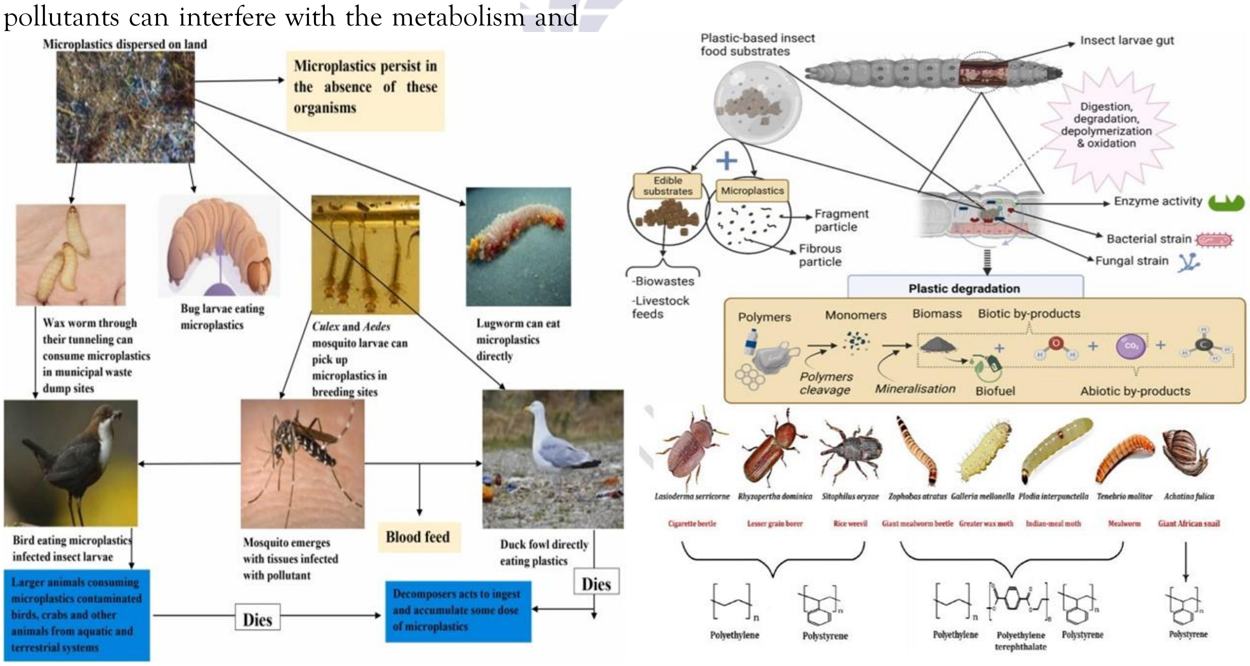

Figure 05. MPs disrupt normal larval insect growth by contamination in the gastrointestinal tract.

This physical interference is capable of decreasing the food intake that is taken in reality. Insects may also be affected in terms of developmental timing by microplastics. In other studies, it is found that insects that are subjected to plastic particles at an early age in their development underwent delayed metamorphosis (Wang et al., 2021; Zhou et al., 2021). Late development can lower levels of survival in the natural environments. The other issue is that microplastics can interfere with hormonal growth movements. Plastic substances like biphenyl's and phthalates have been known to be endocrine disruptors in most organisms (Rillig et al., 2019; Zhang et al., 2020).

The reproductive success is a significant parameter that defines the stability of the insect population. Exposure to microplastic has been demonstrated to affect the process of reproduction in multiple insect species (Ju et al., 2019). Consumptive insects can develop physiological stress on the reproductive organs, hormonal regulation when ingesting plastic particles. A study on the stored grain pest *Tribolium castaneum* shows that the exposure to the microplastic can decrease the egg production. Females who were exposed to plastic particles had a lower number of eggs in comparison with those who were brought up in clean environment (Kim and An, 2019).

Moreover, chemicals present in plastics can interfere with the endocrine system that controls reproduction. Endocrine imbalance may influence the development of eggs, fertility, and survival of the offspring (Zhou *et al*., 2021). These impacts might be transgenic. Due to the important functions of insects in pollination, decomposition, and pest control, a decrease in reproductive success may have impacts on the functioning of an ecosystem. The study of the effects of microplastics on insect reproduction is of relevance in making ecological predictions, thus (Zhang *et al.,* 2020; Wang *et al.,* 2021).

Some of the first signs of the environmental stress of insects are the changes in behavior. Microplastics may change the feeding habits, mobility patterns, and socially interacting ability (Ju et al., 2019). This type of behavioral adjustment can decrease the survival and reproductive success. Research on the bumblebees including *Bombus terrestris* indicates that microplastic pollutants have the potential to influence foraging behavior. The bees that have access to contaminated food sources can spend more time resource searching or be less efficient with gathering nectar and pollen (Al Naggar et al., 2021).

Insects might also be affected by microplastics in predator avoidance. Physiologically stressed insects may respond slower to predators (Zhou et al., 2021). These changes have the potential of leading to a greater death rate in natural environments. The other potential behavioral impact is decreased mobility. Plastic in the digestive system can reduce the availability of energy to decrease movement and activity (Kim and An, 2019).

They are defended against pathogens and the environmental stressors by insect immune systems. The exposure to microplastic can impair immune responses because it leads to physiological distress and inflammation (Wang et al., 2021). Plastic particles are capable of causing immune response when they get into the insect bodies. Experiments with the microplastic insect Drosophila melanogaster have demonstrated that exposure to microplastic is capable of elevating oxidative stress. Oxidative stress destroys cells and can undermine the immune defenses (Zhou et al., 2021).

Consequently, insects might be exposed to infections. Microplastics can also affect the immune related gene expression. The capability of insects to synthesize antimicrobial peptides can also be altered by changes in the expression of genes (Zhang et al., 2020). Such suppression of the immune system can predispose one to pathogenicity. The other issue is that microplastics have the capacity to hold microorganisms on their surfaces. Insects that feed on polluted plastics might be subjected to dangerous bacteria and fungi (Jacquin et al., 2019).

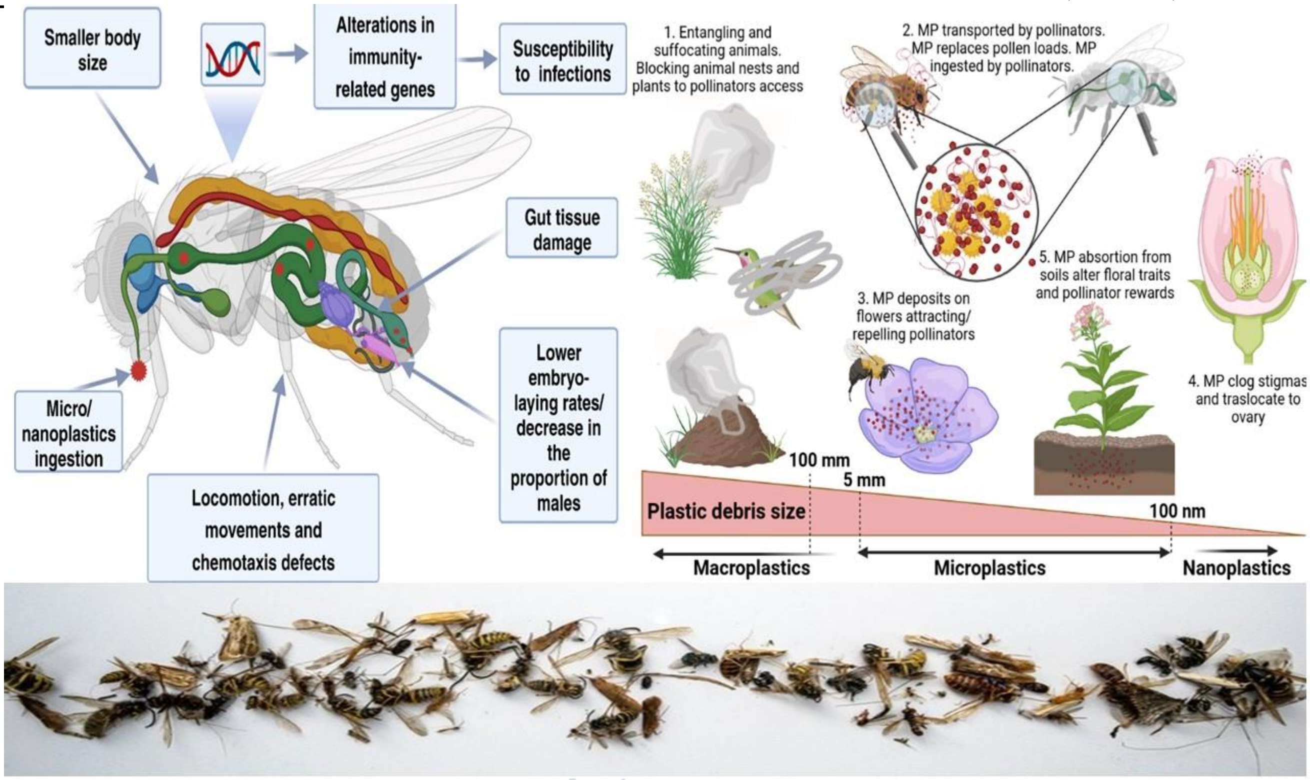

Figure 06. Nanoplastics ingestion by insects alter their immunity related genes and also effect pollination

Ants have significant ecological values in the capacity of soil engineers, predators, and seed dispersers. Since numerous species of ants can forage on the surfaces of plants and in soil, they are one of the most exposed to microplastic (Zhou et al., 2021). The research on Lasius Niger species gives a clue to the influence of small plastic debris on social insects. When ants were put in controlled experiments they were exposed to microplastics which resulted in altered foraging behavior. Employees were gathering contaminated food and frequently discarded it upon coming in touch with plastic particles (Wang et al., 2021). The present behavior implies that ants can detect and react to plastic pollution.

The microplastics can also be stored in the ant nests in case workers carry polluted materials. The exposure to plastic pollution by these particles may happen to larvae and queens (Zhang et al., 2020; Zhou et al., 2021). This may have long term accumulation impacting on colony health. The other observation that is significant is the possibility of interfering with colony productivity. The decline in the efficiency of workers and larval development can lower the growth of the colonies (Ju et al., 2019).

Microplastics and Population Depression of the Pollinators

There is a decrease in the populations of pollinators worldwide, where several environmental factors are to blame. The microplastic pollution has also recently become the possible contributing cause (Rillig et al., 2019; Zhang et al., 2020). Pollinators are exposed to plastic particles in the soil, air and plant surfaces. *Bombus terrestris* and honeybees are particularly susceptible to the species that can have close contact with the reproductive structures of plants. When microplastics settle on flowers, these insects may become polluted by nectar and pollen (Al Naggar *et al.*, 2021).

Microplastics can as well react with other environmental stresses like pesticides and habitat loss. The exposure to a combination may alter the adverse impact on pollinator health (Zhang *et al.*, 2020). The solution to protecting the populations of pollinators is to deal with emerging pollutants like microplastics. The decrease of plastic pollution of the agricultural landscape may contribute to the preservation of pollination services that contribute to food production (Al Naggar et al., 2021).

Microplastics in agricultural systems may be transferred through food webs through trophic transfer. This happens when other living organisms in the lower trophic chains ingest the plastic particles and are then preyed upon by other organisms (Huerta Lwanga et al., 2017). Consequently, plastics can be deposited to a greater trophic level. The microplastics may get into herbivorous insects that feed on polluted plants, which may be deposited by soil or through the air. Predators like birds, reptiles, or predatory insects can then consume such insects (Zhang et al., 2020). This is the route through which the plastics pass through the food webs on earth. As an illustration microplastic may be consumed by herbivorous insects such as *Locusta migratoria* when they are feeding on the contaminated crops. The insect predators can thus be at risk of plastic pollution (Huerta Lwanga et al., 2017).

The trophic transfer also creates the issue of bioaccumulation of plastics and related chemicals. Toxic substances are also prone to be absorbed by microplastics and be deposited in the tissues of predators (Zhou et al., 2021). This pollution can impact on the upper trophic levels. The role of the movement of microplastics in food chains will help analyze the risk of ecological and human health. Further studies are required to define the effects of plastic pollution on the stability of the terrestrial ecosystem and agricultural sustainability (Zhang et al., 2020).

Microplastics Bioaccumulation

Plastics that are smaller in size have become widely identified as contaminants with the potential to accumulate in terrestrial food webs. When deposited into the soil of the agricultural sphere, the mentioned particles may be retained in soil microorganisms including burrowing worms, insects, and other invertebrates, which are the foundation of most terrestrial food chains (Huerta Lwanga et al., 2017).

Invertebrates (snails) in sand may consume the plastic particles when sucking organic matter. The particles can stay in the digestive tract or build in tissues and expand the exposure to pollutants that attach to plastic materials (Huerta Lwanga et al., 2016). These insects which feed on infected organisms may then also consume these particles. Some studies indicate that consecutive trophic transfers may cause a substantial amount of microplastics in the ecosystems. This accumulation can interfere with the nutrient cycling and energy flow within agro landscapes (Wang et al., 2021).

Ecosystems are organized with predator prey dynamics, as they are essential processes that allow population regulation. Microplastic pollution is likely to affect these relationships, changing the behavior and physiology of predators and prey (Zhou et al., 2021). Alterations in feeding habits or locomotion may have a major impact on the ecological equilibrium. Considering the example, herbivorous insects in contact with microplastics could be less energetic and move more slowly. These modifications might expose them to predation by insects like *Coccinella septempunctata* that regularly consume smaller insects (Zhang et al., 2020). The enhanced predators might be temporary due to increased vulnerability.

Nonetheless, when predators eat the contaminated prey, they also subject themselves to its effects. The second cause is indirect ingestion of microplastics by the prey, which may cause predator degradation or lowering the success of reproductive success (Huerta Lwanga et al., 2017; Zhou et al., 2021). This is a two-way exposure which makes ecological results more difficult. A second potential impact is the change in prey detection and prey hunting behavior. When microplastics decrease the level of sensory functions or energy in predators, this reduces the efficiency of hunting as well (Khan et al., 2023).

An important measure of ecosystem health and strength is biodiversity. Agricultural ecosystems are diverse in terms of communities of soil organisms, insects, plants and microorganisms that collectively ensure an ecological balance (Rillig et al., 2019). Plastic particles have the ability to alter such physical properties of soil like aggregating and porosity. Such alterations can affect the plentiful amount and livelihood of ground-dwelling living beings, which can lower the level of species (Qi et al., 2020). Some species might be more plastic sensitive as compared to others. As an example, *Folsomia candida* invertebrates have been reported to reproduce less when placed in soils with microplastic. A decrease in such organisms would break the food webs and nutrient recycling of soils (Ju et al., 2019).

Microplastics can also cause the introduction of chemical pollutants which pose an additional risk to biodiversity. Plastic additives and taken up pesticides may have impacts on many species at the same time (Zhou *et al.*, 2021).

Ecosystem Services Affected by Nanoplastics Pollution

Ecosystem services refer to benefits that human beings receive in natural ecosystems. These services in agricultural systems are pollination, pest control, nutrient cycling, and soil fertility (Rillig *et al.*, 2019). These processes can be endangered by microplastic pollution. One of the key ecosystems is pollination. *Apis mellifera* insects are significant pollinators of crops in the world. Microplastics can disrupt the health of pollinators and decrease the effectiveness of pollination (Al Naggar *et al.*, 2021).

Another essential ecosystem service that is offered by useful insects is natural pest control. Parasitoids and predatory insects assist in controlling the population of pests in crops (Power, 2010). In case such organisms are harmed by the nanoplastics pollution, the pest outbreak could become frequent. Microplastic can also affect the soil processes like decomposition and nutrient cycling. Organisms in the soil that decompose organic matter can be affected by plastic particles and become less active (Qi et al., 2020).

The microplastics have been found to absorb different chemical pollutants of the immediate environment. They have a great surface area and are hydrophobic, which means that they can be used to bind substances like pesticides and heavy metals (Wang et al., 2021). A consequence of this is that plastics can be vectors of harmful chemicals in soil ecosystems. As an illustration, the heavy metals such as Cadmium may be sticking on the plastics and then washed away through the soil. By consuming such particles, organisms can be exposed to the plastic material as well as the contaminants (Zhang *et al.*, 2020). It is important to understand that nanoplastics are carriers of pollutants that can be taken into consideration when determining the environmental risk. Agricultural chemicals are potentially profoundly affected by these particles in the distribution and toxicity of different particles in an ecosystem (Deng et al., 2024).

There are usually several contaminants in agricultural soils. Fertilizers, pesticides, and herbicides are some of the fertilizers that microplastics can contact (Zhang et al., 2020). Such interactions can have complicated effects on the environment. Agrochemicals can be absorbed onto plastic particles and their movement in the soil can be changed. The process can affect the distribution of chemicals around the roots of plants (Zhou et al., 2021). There are instances where plastics can enhance the persistence of the chemicals.

Plants that are planted in contaminated soils may thus have combined stress caused by agrochemicals and plastics. It can affect the growth of plants, the uptake of nutrients, and root development (Qi et al., 2020). Microplastics can also alter microbial activity in soil as per nutrient cycling. As an example, there could be a case of disturbed root development in soils that have plastic particles and pesticides such as Triticum aestivum. In some circumstances, these interactions can decrease crop productivity (Wang et al., 2021). These complicated interactions are to be studied further. The analysis of combined effects of the pollutants will aid in enhancing the environmental risk analysis of agricultural systems (Maddela et al., 2023).

Two of the biggest environmental issues in the contemporary agriculture are climate change and plastic pollution. Such problems can also interplay with each other in a manner that can increase ecological effects (Sunitha et al., 2021). Temperature fluctuations, rainfalls, and severe weather patterns may alter the distribution of microplastics in the soils. As an illustration, when there is higher rainfall and flooding, plastic particles are likely to be carried across farmlands. The processes can result in the build-up in the low lying fields and waterways. This redistribution may have an impact on the quality of soil (Villarrubia-Gómez et al., 2018).

There is also the likelihood that larger plastic products break down into smaller fragments through higher temperatures owing to shift in atmospheric conditions. Plastic covers on agricultural land can be broken down quicker in the presence of strong sunlight and heat (Sobhani et al., 2020). Climate stress can also cause the plants to be more prone to the pollutants. Microplastic contamination can be more vulnerable to crops already in a state of drought or heat stress (Lionetto & Esposito Corcione, 2021). It is important to understand the relationship between the climate change and the plastic pollution. These interconnected issues will demand the application of integrated environmental management strategies (Mintenig et al., 2017).

According to recent studies, it can be considered that the microplastic particles can be consumed by plant roots and carried into plant tissues. This was established in numerous crop species, such as Lactuca sativa (Li et al., 2020). This uptake also brings up the issue of possible contamination of food chain. Micro plastics in the soil may be absorbed by plant roots via microscopic openings or ruined root tissues. When within the root system, the smaller plastic particles can be transported upwards using the vascular tissues (Zhang et al., 2020). This process can spread the plastics all over the plant. In controlled experiments, experimental studies have been able to find plastic particles in plant leaves and stems. These results show that vegetation can serve as a source of entry of microplastics into land-based food webs (Alimi et al., 2018).

The uptake of the plant can be determined by the size of the particle, the type of polymer, and the status of the soil. Roots can take in smaller particles than larger particles. The possibility of plant uptake has made the need to monitor microplastic pollution in agricultural soils important although research is still at its infancy (Galgani et al., 2015).

Germination of a seed is an important step in the growth of a plant as it dictates the crop development and yield. Microplastic contamination can have an effect on germination by changing the physical and chemical properties of the soil (Qi et al., 2020). Water availability of seeds may be influenced by changes in the soil structure. Crops like Zea mays have been tested experimentally where some microplastics have been found to inhibit germination. Plastic particles can also disrupt the absorption of water or cause physical barriers around the seeds (Zhou et al., 2021).

Moreover, plastic additives can be washed into the soil and affect the physiology of the seeds. Seed metabolism could be influenced by the exposure to chemicals at the early stages of development. Nevertheless, other studies show few effects according to the type of plastic and concentration. These differences indicate that environmental factors have a strong impact on outcomes (Zhou et al., 2021).

Germination of plants may as well be affected by microplastic contamination. Nutrient availability to plants can be changed under the influence of different alterations in soil structure and microbial activity (de Souza Machado et al., 2018). Such transformations have the ability to affect root growth and biomass of vegetation. Fibrous plastic particles can affect the water retention as the porosity of soil can be increased. Under certain conditions, it can improve the growth of plants (Qi et al., 2020). Plant species like *Oryza sativa* can be retarded in high levels of microplastics. Experimental studies have led to decreased uptake of nutrients and root damage (Zhang et al., 2020). Microplastics can also have an effect on the stress of plants. Plastics can cause the growth of plants to generate stress-related enzymes and antioxidants (Dawson et al., 2018). These impacts are of importance since the productivity of plants will directly influence the food security in the world. Agricultural soils can thus be reduced in microplastic pollution, which contributes to sustainable crop production (Rosati et al., 2024).

The occurrence of microplastics in edible foods has been an issue of concern due to the risk of human exposure occurring in farmland products. Plastic particles may be deposited in agricultural soils by means of mulching films, irrigation with wastewater, and atmospheric deposition (Geyer et al., 2017). When these particles are found in soil, they can be in contact with plant roots and the microorganisms in the environment. Recent experimental research has proposed that some small plastic particles can penetrate plant tissue and be stored in plant edible tissue areas (Frias & Nash, 2019).

Indicatively, some research on *Lactuca sativa* has indicated the existence of nano scale plastic particles in the root tissues and leaves. The absorption process is probably associated with penetration via root pores or damaged cell walls in certain conditions of the environment (Li et al., 2020). Even though the level recorded in the edible tissues is normally low, the fact that the plastics are present in food crops creates concerns on the long term dietary exposures. The plastic particles that are in crops can also be carrying toxic materials like heavy metals or adsorption of pesticide residues on its surfaces. As human beings eat contaminated produce, the contaminants may potentially move to the food chain (Wright & Kelly, 2017). The other problem is the indirect impact of microplastics on the quality of crops. Plastic contamination might cause changes in plant physiology or nutrient uptake, which would alter the nutritional content of crops (Andrady, 2017).

Techniques of Microplastics Detection in Soil

The agricultural soils have complicated mixtures of microorganisms, minerals and organic substances, and therefore, it is difficult to detect microplastics in agricultural soils. There are a number of techniques that allow the researchers to isolate and identify plastic particles in the soil samples (Bläsing et al., 2018). Density separation involves the high density salt solutions to suspend plastic particles on top of the heavy soil ingredients. Usually, the use of mixtures like NaCl or ZnCl is applied in order to isolate plastics in soil samples (Galloway et al., 2017).

Microscopy is commonly carried out to find out the possible plastic fragments through a visual examination. Nonetheless, it is possible that visual techniques will cause misidentification due to similarity between natural fibers and plastic substances (Zhou et al., 2021). Another step of the detection process is chemical digestion. Plastic particles are identified by using oxidizing agents to remove organic matter in the soil (hydrogen peroxide) before identification (Gigault et al., 2018).

To identify the correct microplastic particles, the sophisticated analytical methods are necessary to differentiate the synthetic polymers and the natural ones. Spectroscopic techniques are now the most popular methods of determining plastic debris in environmental samples (Hidalgo-Ruz et al., 2012). Such techniques examine the structure of materials at the molecular level to ascertain the chemical composition of materials. In this procedure, the researchers are able to identify the common plastics that include; polyethylene and polypropylene.

Raman spectroscopy is another effective method. Raman analysis is a method of studying the vibrations of plastic materials with the help of laser light (Bouwmeester et al., 2015). The technique is useful to determine small plastic particles that may not be easily seen under conventional microscopy. The spectroscopic techniques are frequently used in conjunction with the imaging technologies to plot the contents distribution of the plastics in the soil samples. The combination of these methods enhances the accuracy and efficiency of identifying microplastic (Duis & Coors, 2016).

The impact of microplastics on insects can be studied only with the help of laboratory and field experiments that should be formulated carefully. Scientists usually introduce insects to plastic materials via polluted sources of food or soil (Ju et al., 2019). Through these experiments, scientists are able to see how insects change in terms of physiology, behavior and survival. Drosophila melanogaster is a model insect species and is commonly used in laboratory research due to the known life cycle. Controlled experiments enable the researcher to quantify the growth rates, reproduction, and the stress response with exposure to microplastic (Lackner & Besharati, 2025).

Field studies are also significant in getting to know the actual environmental conditions. The investigators can also observe the abundance of insects in farmland where plastic coating or water irrigation is frequently present (Jambeck et al., 2015). These researches give us the view of the long term ecological impacts. The other method used in the experimentation is the trophic transfer experiments. Insects in such investigations are offered prey containing microplastics that have already eaten, thus enabling the researcher to examine the way in which plastics circulate in food webs (Huerta Lwanga et al., 2017; Zhang et al., 2020).

Enhancing microplastic pollution mitigation in farmland should be achieved through technological advance, enhanced waste management and sustainable farming methods. Farmland plastics like greenhouse covers and mulch films are the biggest sources of soil microplastic pollution (Rillig et al., 2019; Wang et al., 2021). This can be achieved in a great way by enhancing the collection and recycling of these materials to go a long way in eliminating the amount of plastic in soils. It is also possible to ensure that farmers use other materials that produce fewer plastic residues. As an illustration, plant-based plastics (based on biodegradable polymers) are being created to substitute regular plastics in the form of mulching materials (Qi et al., 2020; Zhang et al., 2020).

The invention of biodegradable plastics is an encouraging move towards the mitigation of environmental pollution by agricultural plastics. Polylactic acid is one biodegradable polymer that has received a lot of research attention and it is made of renewable plant materials like corn starch. The agricultural mulch films and packaging materials have made use of polylactic acid plastics (Qi et al., 2020; Zhang et al., 2020). Biodegradable plastics can also help to decrease the number of plastics that settle in soils in the long run since they are decomposed faster than the traditional plastics are. Nevertheless, there are researches that indicate that partial degradation may still result in smaller pieces of plastics (Strand et al., 2021).

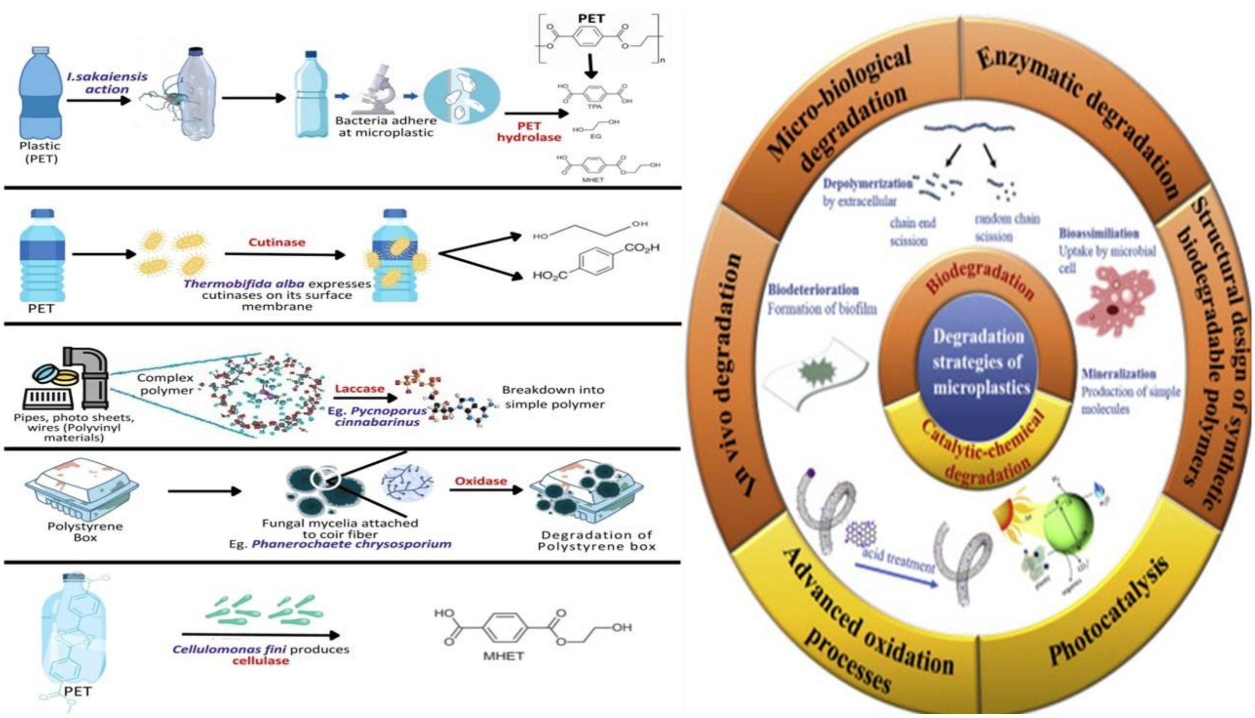

Figure 07. Biodegradation Strategies for microplastics.

The reduction of plastic pollution in agricultural systems is a must because of sustainable waste management. Gathering the utilized plastic films and delivering them to the recycling plants helps to avoid their degradation in the fields. The other measure is the minimization of plastic consumption by the use of alternative farming methods. The use of organic mulching or crop residue management as techniques can eliminate the use of plastic materials (Leslie et al., 2022).

Microplastic pollution needs effective policy frameworks and regulatory initiatives to address the situation. Authorities and global agencies are beginning to see the necessity to manage plastic waste and avoid environmental pollution (Lusher et al., 2017). The possible regulations can be the limitation of single-use plastics and enhanced waste management policies. There are already policies in place in some countries to minimize the use of plastics in agriculture. Global cooperation is necessary since plastic pollution can usually transcend the borders of countries by air and by water bodies. The increasing issue of the microplastic pollution of agricultural ecosystems can be alleviated with the help of strong regulatory frameworks and scientific research (Zubris & Richards, 2005).

Future Studies on Micro plastics

Despite the fact that in the recent years, research about microplastics in agricultural settings has increased at an alarming rate, there is still a lot of knowledge to learn. The topic of the ecological consequences of accumulating microplastics in the soil over time is one of the aspects where future research ought to focus on it (Cox et al., 2019). Researchers should learn more about how microplastics can affect the work of microorganisms, plants, and insects in the long run in relation to soil. Field experiments, carried out over a long period, will be especially useful in answering these questions (Thompson et al., 2024). The other research priority is the development of the standardized approaches to the measurement of microplastics in the samples of the environment. The similarity in methodologies would enable researchers to carry out a comparison of the findings of other researchers in various geographic areas. The risks posed by entry of microplastics into the human food chain by agricultural products also need to be explored in future studies. It will be necessary to advance the field of interdisciplinary research to handle the complicated problem of plastic pollution (Huerta Lwanga & Santos-Echeandía, 2021).

Conclusion

Agricultural ecosystem microplastic pollution is a novel environmental issue with strong implications in the health of soils, insect biodiversity, and the general workings of agroecosystems. Plastic mulching, wastewater irrigation, use of sewage sludge, and compost are some of the activities in the agricultural sector that add significantly to the amount of microplastics found in the soils. When found in the soil environment, the particles may alter the soil structure, water retention, nutrient cycling and microbial dynamics, which ultimately have effects on crop productivity and ecosystem stability. Microplastics are also having direct and indirect impacts on soil organisms and insects by introducing terrestrial food web via contaminated plant tissues, soil ingestion, and pollen resources. Honeybees and other pollinators can have disrupted gut microbiota, oxidative stress, and lack of nutritional efficiency caused by exposure to microplastics. Moreover, microplastics have the ability to serve as vectors of toxic substances and pathogens, posing a greater ecological threat in agricultural sceneries. Despite the rapidly growing body of research on terrestrial microplastics, there are still some significant gaps in understanding their ecological implications and their accumulation in the food webs of the soil. Future research ought to be directed towards the long-term field experiments, better monitoring method and creating biodegradable substitutes to the standard agricultural plastics. To reduce microplastic pollution and enhance the stability of agro ecosystems in the future, the sustainable use of plastic resources with the environmentally friendly agricultural practices will be crucial.

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