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ADVERSE EFFECTS OF MICROPLASTIC ON AGRICULTURAL SOIL

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ABSTRACT: A new worldwide environmental emergency that has significant effects on crop yield and food security is the contamination of agricultural soils by microplastics (MP). This thorough analysis summarizes the state of science about the detrimental impacts of microplastics on crop growth, with a focus on the molecular and chemical processes that underlie these effects. This paper analyses recent studies and shows that microplastics cause oxidative stress and interfere with vital physiological functions, reducing plant biomass by 13% and chlorophyll content by 28% on average. According to the research, the main ways that smaller microplastic particles (less than 100 nm) cause harm are via disrupting cellular processes, destabilizing membranes, and interfering with nutrient uptake pathways. In order to address this escalating environmental concern, this research offers crucial insights for creating mitigation methods and guiding agricultural policy.

KEYWORDS : Microplastics, agricultural products, soil ecosystem, natural waterbodies, environment ,contamination, pollution ,chemically induced, inorganic fertilizers, sewage treatment

INTRODUCTION: One of the most urgent environmental issues of the twenty-first century is the widespread prevalence of microplastics (MPs) in terrestrial ecosystems. MPs, which are plastic particles with a diameter of less than 5 mm, have entered agricultural soils all over the world by a variety of means, such as plastic mulching, the application of sewage sludge, atmospheric deposition, and the deterioration of agricultural products. According to recent estimates, sewage sludge alone may contribute more microplastics to agricultural soils each year than are already present in the world's oceans. With concentrations rising sharply over time, especially in regions where organic or inorganic fertilizers are used, agricultural soils are important sinks for the buildup of microplastics. The physiology of plants, soil health, and eventually the world's food security are all seriously threatened by this contamination. Microplastics and soil-plant systems interact in intricate ways through a variety of chemical, physical, and biological processes that collectively hinder crop development and growth. In order to ensure sustainable agricultural practices and create effective mitigation methods, it is imperative to comprehend these mechanisms. This study offers a thorough examination of the ways in which microplastics chemically disrupt plant growth processes, shedding light on the molecular mechanisms by which these contaminants have their harmful impacts. Few studies have truly examined the effects of microplastics on plants and agriculture, despite the fact that many concentrate on their effects on fauna. It was discovered. that sludge from sewage treatment facilities and wastewater is frequently utilized as soil additions for agriculture, resulting in a significant amount of microplastics in farmlands [1]. Wastewater and sewage treatment facilities actually contribute significantly to the environmental microplastic problem by releasing sludge and effluents that include microplastics. There are already microplastics in natural waterbodies through purification procedures, after which the microplastics are released back into the environment [2]. Sludge use for agricultural purposes causes localized contamination with microplastics, which then spreads via runoffs, air, and soil biota [3]. The effects of high concentrations of microplastics in agricultural soil on crop growth and the threat to the food supply are the subject of relatively few studies. Therefore, the purpose of this brief review is to provide a succinct overview of the effects of soil microplastics on crops and agriculture.

CHEMICAL PATHWAYS BY WHICH MICROPLASTIC IMPAIR CROP GROWTH :

- **Additive leaching and weathering products :** Bisphenols (BPA/BPS), plasticizers (phthalates), UV stabilizers, and pigments are found in the majority of agricultural plastics. These low-molecular-weight substances are released into soil porewater more quickly as a result of weathering, where they disrupt hormones, prevent roots from growing longer, and interfere with microbial activity. Chemical toxicity is consistently reported when leachates accumulate, however field investigations indicate that cumulative effects may be partially obscured by the aeration benefits of the particles themselves [4].
- **Sorption-desorption and vectoring of co-contaminants:** MPs/NPs absorb heavy metals and pesticides because of their large surface area and hydrophobicity. Desorption is triggered by variations in rhizosphere pH and ionic strength, which efficiently transport pollutants to plant roots. Studies reveal synergistic toxicity: in lettuce, polystyrene MPs in combination with either lead or cadmium resulted in greater oxidative damage and growth suppression than either stressor by itself [5].
- **Disruption of soil nutrient cycling and chemical fertility:** MPs disrupt N and P conversions by changing the structure of microbial communities and the activity of enzymes. This lowers the amount of nutrients accessible to plants, which frequently results in changes to cation-exchange capacity and 15–25% decreases in N and P availability [6]. These alterations show up as decreased biomass output, decreased nutrient utilization efficiency, and symptoms of nutritional deficiencies.
- **Plant uptake of Microplastic and chemically mediated cellular stress :** Through apoplectic and simplistic pathways, NPs can enter roots, move to shoots, and settle in organelles. They cause DNA damage, lipid peroxidation, reactive oxygen species (ROS), and phytohormone alterations (auxin/ABA) inside tissues [7]. As a result, there is less chlorophyll, less root and shoot growth, and compromised stomatal function

OURCES AND DISTRIBUTION OF MICROPLASTICS IN AGRICULTURAL SYSTEMS :

Plastic mulching, contaminated compost or fertilizer, irrigation with contaminated water, atmospheric deposition, and the degradation of farm equipment and packaging are some of the ways that microplastics get into agricultural soils. The primary sources are mulching films and sewage sludge.

Source	Plastic Types	Particle Size	Typical Abundance
Sewage sludge	PE, PP, PET, PVC	50-500 μm	up to 18,760/kg
Mulching films	PE, PP	7 μm-5 mm	~1,075/kg
Compost	PE, PP, PS, PET	1-5 mm	11-895/kg

The two main categories of microplastic sources are primary and secondary . **Primary microplastics** are made with particular uses in mind, including drug vectors, harsh chemicals for cosmetics, and engineering-related applications like air blasting. After entering wastewater, microplastics gradually build up in the environment and are challenging to remove with sewage disposal systems .[8]

Secondary microplastics are created when larger plastics break down into smaller pieces over time due to a number of complex environmental conditions, such as UV radiation, wind temperature, and wave action . frequent use of plastic-based items might cause fragmentation and the creation of new microplastics. Additionally, one of the main causes of microplastics in the environment is plastic emissions from vehicle traffic, which include deterioration of tires, brakes, and road markings . The global average of microplastic emissions from road vehicle tire abrasion was 0.81 kg.year-1.capita-1. About 2% of all tire disintegration emissions in the Netherlands are caused by abrasion from aviation tires, aside from vehicles .

According to estimations ranging from 760 to 4500 t.y-1 [10], artificial grass is also a significant secondary source of microplastics. As a result, a variety of microplastic types are released into ecosystems and natural habitats. In contrast to the ocean's primary land-based sources of microplastics (80%), coastal tourism, commercial and recreational fishing gear (18%), and shipping and marine industries (such as oil rigs, aquaculture, etc .Landfills soil amendments
,sewage sludge, land application and wastewater irrigation are some of the ways that microplastics get into soil. Additionally, by feeding, digesting, and excretion, soil fauna break down plastic trash in the soil into microplastics .

PRIMARY SOURCES /DIRECT SOURCES OF MICROPLASTICS IN AGRICULTURE SOIL :

Plastic mulching : There is no apparent way to control or interrupt the massive yet undetected plastic sources that are constantly flooding the soil and causing microplastics to settle. Mulch film, composed of polyvinyl chloride and polyethylene, has gained popularity in global agriculture due to its many economic advantages, such as improved fruit quality, greater harvest, and water use efficiency [11]. The global market for plastic agricultural films was 4 million tonnes in 2016, and by 2030, it is expected to grow at a rate of 5.6% annually .

When agricultural soils are plowed and farmed, shear loads on plastic waste in fields will also be felt, perhaps breaking up already delicate polymers . In the three regions of India, microplastics are present in 37.97%, 35.07%, and 36.99% of tomato fields that employ the Plastic Mulching technique (Fig. 1),[12].

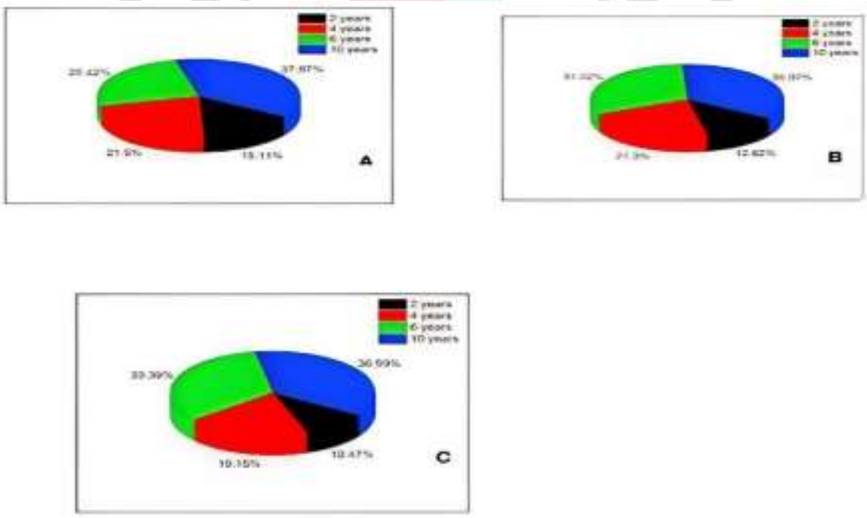

Fig.1:Effects of the duration of plastic mulching on percent distribution of plastic residues at different soil depths (A)0-10cm(B)11- 20cm(C)21-30cm by Kumar et al. (2021)[12].

Littering : There is now a greater diversity and range of microplastic trash in the soil due to the overabundance of plastics and haphazard or inadequate management practices [13]. A significant amount of plastic waste can produce microplastics in aquatic settings . Approximately 6.3 billion tons of plastic waste were produced worldwide between the 1950s and 2015, of which 4.97 billion tons ended up in landfills and natural areas

Silage and Bale Nets : The first study to address the problem of microplastics in soils at the agricultural scale, the usage of plastics in the form of wrapped grass bales and silage can pollute livestock diets and then infiltrate the soil through excretion.

Twine : There are several agricultural applications for polypropylene (PP) twine . For important crops like tomatoes, crucifers, sweet peppers, etc., twine is useful for securing plants to stakes. It is used to join plants and prevent them from tumbling over when growing bananas . The twine is often cut during harvesting and haphazardly discarded in the fields, where it becomes microplastics in the soil. Initiatives are in place to encourage the use of biodegradable twine, which may be collected and composted with plant waste (Biothop et al. 2019)[13].

Plastic used for plant plantation : The amount of microplastics in soil samples is increased by plastic films and non-woven plastic fabrics, such as those used in greenhouses, polytunnels, shade nets, and wind barriers. Soil samples taken from farms without greenhouses had fewer microplastics than soil samples taken from farms with greenhouses for an equivalent productive area[14]. The authors observed a range of 1000 3786 MP kg particles at sites where greenhouses were first used in the 1980s [14] also found that soil samples taken in greenhouses had an average of 2110 MP kg¹ of microplastics, while soil samples taken outside had an average of 310/kg.

Improper Storage : Svensk Ensilageplast Retur claims that plastic can be discovered in large quantities on agricultural farms. Because they sometimes lack the time or technical expertise to properly clean and preserve the spent plastics, farmers must make extra steps to collect and store them. Plastic waste needs to be disposed of in a dry location that is protected from the wind in order to stay clean and prevent it from flying away. Inappropriate plastic storage on farms is one of the main causes of the significant issue with plastic waste management in agricultural areas.

SECONDARY SOURCES/INDIRECT SOURCES OF MICROPLASTICS :

Sewage Sludge : Microplastics are contaminated by sewage and wastewater treatment plant sludge, and they can accumulate in soil as a result of frequent sludge use [15]. There are several ways that microplastics might get into wastewater treatment plants . Sewage is contaminated by microplastics from car tires, polymer fibres discharged from washing fabrics, plastic masterbatches that seep from the plastic manufacturing plant, and microbeads from personal cleaning and care products. Throughout the sewage treatment process, these microscopic particles move and settle. While most of them are separated during the sedimentation phase of sewage treatment and finally find their way into the wastewater sludge, others are discharged from the sewage system .

Irrigation: Numerous studies have confirmed the existence of microplastics in agricultural irrigation water supplies . The main sources of irrigation water in the world include rivers, lakes, reservoirs, and aquifers. In some places with limited water supplies, sewage is also used for irrigation 16]. High levels of microplastics are still present in the purified wastewater even if a significant portion of them may be removed throughout the sewage treatment process . Significant levels of microplastics have been found in rivers, lakes, reservoirs, and aquifers in a number of investigations . Irrigation will transfer microplastics from water reservoirs to the soil, resulting in a concentration of microplastics in the soil.

Flooding and street runoff : In addition to intentional irrigation, street runoff and floods are important pathways for the movement and buildup of microplastics in the soil [16]. Uncontrolled trash dumping close to roads, as well as rubber tire abrasion into soils, can be brought about by street runoff and floods. Some of them are already microplastics, while others are gradually transformed into microplastics as a result of several interactions with the environment.

Compost: Microplastics may be able to penetrate the soil through the addition of compost. Once organic waste has been fermented and composted, it is frequently repurposed as humus, minerals, trace elements, and nutrients in fields. For instance, it has been demonstrated that plastics are included in composts formed from biological waste due to inappropriate disposal and inadequate waste classification [16]. In a Bonn composting facility, the amount of plastic particles visible to the naked eye ranges from 2.38 to 180 mg kg, indicating that microplastics are present in organic compost [16]. In a Bonn composting facility, the amount of plastic particles visible to the naked eye ranges from 2.38 to 180 mg kg, indicating that microplastics are present in organic compost [16]. 24MP particles/kg, ranging in size from Imm to 5mm, were present in the compost made from German green clipping and municipal organic waste. Additionally, according to Crossman, biosolid applications may lead to notable rates of microplastics export even when present restrictions are followed. After an annual launch with 30 and 15 sludge composts, respectively [21] found that the overall concentrations of microplastics in soils are 545.9 and 87.6 items/kg, which is significantly greater than soil without compost application.

Input From The Atmosphere : One important way that microplastics are deposited on land is by atmospheric transmission. The accumulation of fibrous microplastics both indoors and outdoors was first measured and recorded by a study [14]. The settling flow of atmospheric microplastics outside was found to be between 0.3 and 1.5 fibers m^3. In a remote mountainous catchment area, relative averages of about 249 fragments, 74 pieces of film, and 43 fibers could be deposited daily .

Transportation of microplastic to agricultural soil : Migration is a crucial component in prolonging the impact of microplastics in soil. It encompasses both vertical and horizontal mobility, as well as biological and non-biological transportation . Microplastics can be carried through surface soil by wind or surface runoff The fact that microplastics are found in deep soil suggests that they travel downward. Additionally, through root development and movement, root water extraction, and other mechanisms, the bioturbation of plant roots in soil may affect the translocation of microplastics. Soil fauna may aid in the vertical and horizontal movement of microplastics in the soil. Earthworms and collembola species have been found to transfer and disseminate microplastics through adhesion or excretion [17]. Additionally, the dry environment causes soil fissures that let microplastics reach deep soil .

ADVERSE EFFECT OF MICROPLASTIC ON AGRICULTURAL SOIL AND CROP GROWTH :

The nature of the soil affects the migration of microplastics, and microplastics alter the structure and function of the soil as well as the diversity of microbes . These changes may have an impact on the health of plants and animals as well as potentially jeopardize the safety and quality of food, which could ultimately endanger human health. Significant residual plastic layer in the soil has been shown to affect soil microbial activity and abundance, decrease soil-saturated hydraulic conductivity, and ultimately affect soil fertility .

Impact on Soil Structure : Soil nature may be the primary parameter for evaluating the threats that microplastics pose to terrestrial ecosystems due to their ability to interact with various soil characteristics . Microplastic particles can pierce soil clumps and aggregations to varying degrees; they do so more firmly in linear kinds and loosely in fragment types[18]. Additionally, Polyester fibers may greatly increase capacity while lowering bulk density and water-stable aggregation; however, there are no discernible patterns in the effects of polyethylene (PE) and polyacrylic acid on water-holding capacity. Consequently, different types of microplastics have different effects on soil. Different types of microplastics have different effects on soil. Wan examined the effects of adding microplastics on water evaporation and desiccation cracking in two clay soils and discovered that both are significant and increase with increasing microplastics concentration. Microplastics have also been shown to affect soil permeability and water retention, which affects water evaporation . These results suggest that microplastics can alter the soil water cycle, worsen soil water scarcity, and affect the movement of pollutants through fissimes into deep soil layers.

Soil Fertility and Nutrient: Soil enzymes with a high catalytic capacity are closely linked to a number of soil biochemical processes. These enzymes also act as an indicator for determining the fertility of the soil and are crucial in controlling the soil nutrient cycling process for nutrients such as C, N, and P. Microplastics-Carbon may be masked as a major human-caused component of the soil organic carbon pool since microplastics contain polymer chains. Consequently, state that the effects of microplastics on sail are mostly determined by the amount of microplastics present as well as the duration of exposure.

Soil Microorganisms: Researchers have found a strong correlation between soil microbial activity and soil nutrients and features [19]. Compared to non-microfiber-structured soils microbial development is likely to be more significantly impacted by changes in the physical environment of the soil, especially soil aggregation, which has been demonstrated to include linear microfibers. Additionally, the proportions of anaerobic and aerobic microorganisms may shift as a result of microplastics' effects on soil porosity and wetness, which may also impact the transport of oxygen in the soil . Native microorganisms may also go extinct as a result of changes in pore spaces brought on by microplastics.

Native microorganisms may also go extinct as a result of pore space changes brought on by microplastics . Additionally found that the addition of microplastics significantly changed the composition of the microbial community and caused a sharp decline in substrate-induced respiration (SIR) levels, indicating that microplastics caused changes in the function of soil microbes. Dissolved organic matter (DOM) has been connected to both eutrophication and the greenhouse effect because it provides microorganisms with a substrate and a significant supply of carbon. Modifications in DOM caused by microplastics may have an effect on microbial populations and sail function .

Soil contamination : Microplastics' increasing importance as an ecosystem stressor affects soil biophysical properties as well as soil health and function, leading to complex alterations in the environmental behaviour of other soil contaminants[11]. Microplastics' high specific surface area and high adsorption capacity allow them to adsorb harmful contaminants like antibiotics, heavy metals like zinc, copper, and lead, perfinorochemicals (PFOS), and toxic organic chemicals like polybrominated diphenyl ether (PBDE). They also contain additives like diethylhexyl phthalate (DEHP), a common organic pollutant used in the production of plastic .

Transfer along food chains : The ecological and health risks associated with exposure to microplastics are the most concerning discoveries in the research on microplastics in Stil (Guo et al, 2020, Sarker et al, 2020, Kumar et al. 2020, Schwabl et al. 2019). Food chain models and field tests support the idea that microplastics can move up the food chain from prey (at a lower nutritional level) to a predator (at a higher nutritional level) (Guo et al. 2020). Huerta Lwanga et al. (2017) have provided ample evidence of the transmission of both macro and microplastics from soils to hens in traditional Mayan household gardens in Southeast Mexico. The human digestive system contains microplastics, as evidenced by their recent discovery in human feces and adult colectomy tissues (Ibrahim et al. 2021).[20]

Uptake of Microplastics by Plants : Claim that the presence of microplastics would change the soil's chemical and physical characteristics, which would change the root system and the vegetative phase and hinder plant growth. Several recent studies have demonstrated the detrimental effects of microplastics on plants, such as wheat. Perennial Vicia faba [21]. Polystyrene Microplastics (PS-MPs) have been shown to cause genotoxic and oxidative damage to hydroponic Vicia faba, as well as evident growth suppression. Using laser confocal scanning microscopy, a significant number of 100 nm PS-MPs were discovered gathered in root tips .

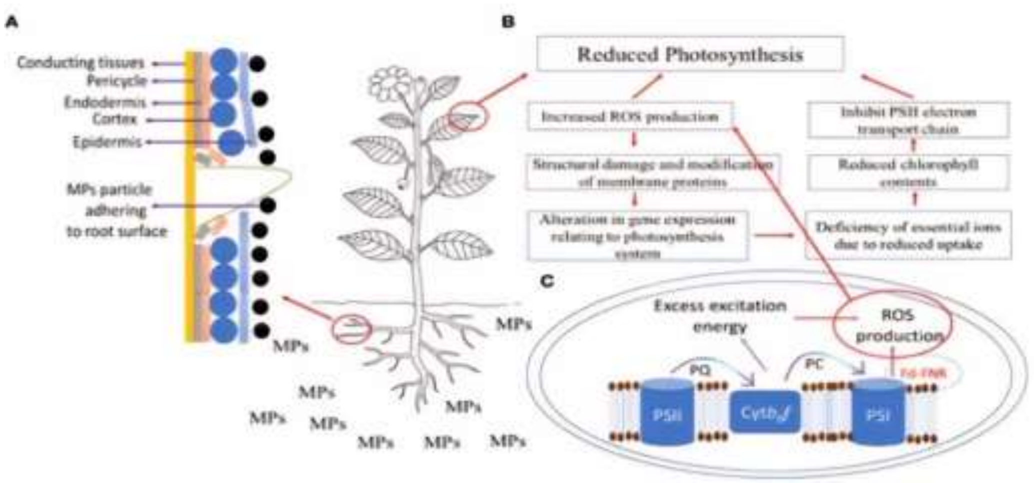

Figure3: 3 (A) Entry of microplastic particle via cracks on newly developed roots[25], 3(B) effects of microplastics (MPs) on photosynthesis, where QA-receptors (QA), photosystem ll (PSI!), photosystem I (PSI) plastocyanin (PC), cytochrome b6f complex (Ctybf, Ferredoxin-NADP+ reductase (FNR), ferredoxin (Fd)[26], 3(C) ROS production in chloroplast under MPs stress[27]

Agricultural Production: In the early stages of crop development, soil microplastics can directly injure crops by physically obstructing the roots or seed capsule apertures [22]. Exposure to microplastics can have extremely short-term negative effects on the development of food plants as early as six days after seeding. Additionally, even biodegradable plastic bags remain unaltered after 27 months in soil due to the remarkable persistence of polymeric plastic particles[23]. It is commonly known that microplastics can impact the growth of agriculturally significant plants through direct absorption from soils via apoplectic and simplistic pathways, as well as dissemination to the entire plant via the vascular system. From the perspective of agricultural output, Microplastics generally have a detrimental influence on crop productivity.[24]

CONCLUSION: It has been demonstrated that microplastics have a variety of effects on plants and crops. Microplastics change the activity of enzymes at the cellular level and have the capacity to induce oxidative damage and genotoxicity. Additionally, some plant cells and protoplasts have the ability to absorb microplastics. Microplastics have detrimental physiological effects on root growth and seed germination, although it is unclear how long these effects remain and how much of an impact each type and size of microplastic has. It is possible for microplastics to enter plants via roots, accumulate and move to various parts of the plants due to physiologically processes such as transpiration. Microplastics have also been hypothesized to affect plants by changing biophysical properties of soil. However, the knowledge of the impacts of microplastics on plants and crops, and agriculture as a whole, is constrained by the relatively low number of studies in this area. This review suggests additional research to look at the concerns because it also shows the possibility that plants may absorb and internalize microplastics. of microplastic exposure in humans brought on by eating agricultural products.

REFRENCES :

1. Boots B, Russell CW, Green DS. Effects of Microplastics in soil ecosystems: Above and below ground. Environ Sci Technol.2019;53(19):11496–506.

2.Wong JKH, Lee KK, Tang KHD, Yap P-S.Microplastics in the freshwater and terrestrial environments: Prevalence, fates ,impacts and sustainable solutions. SciTotal Environ. 2020;719:137512

3.Nizzetto L, Futter M, Langaas S. Are Agricultural soils dumps for microplastics of urban origin? Environ Sci Technol.2016;50(20):10777–9.

4.Lozano Y.M. Disentangling mechanisms by which microplastic films affect soil–plant systems. 2024.

5.Washington Post (Science Desk). Meta-analysis on microplastics and photosynthesis (PNAS report). 2025.

6.Jia Y, Microplastics as drivers of soil–plant chemical imbalance. 2024 7.Galahitigama H, Phytohormonal

disruptions from nanoplastics in crops. 2025

8.Van Cauwenberghe, L., Claessens, M., Vandegehuchte, M.B. and Janssen,C.R., 2015. Microplastics are taken up by mussels (Mytilus edulis) andlugworms (Arenicola marina) living in natural habitats. Environmental Pollution, 199, pp.10-17.

9.Gieré, R., Sommer, F., Dietze, V., Baum, A., Gilge, S., Sauer, J. and Maschowski, C., 2018. Tire abrasion is a major source of microplastics in the environment. Geological Society of America, 50, p.6

10. Kole, P.J., Löhr, A.J., Van Belleghem, F. and Ragas, A., 2017. Wear and tear of tires: A stealthy source of microplastic in the environment. International Journal of Environmental Research and Public Health,14(10), p.1265.

11. Yang, L., Zhang, Y., Kang, S., Wang, Z. and Wu, C., 2021. Corrigendumto Microplastics in soil: A review on methods, occurrence, sources, and potential risk. Science of the Total Environment, 780, pp.146546.

12. Kumar, M.V. and Sheela, A.M., 2021. Effect of plastic film mulching on the distribution of plastic residues in agricultural fields. Chemosphere,273, pp.128590.

13. Biothop, 2019. Biotwine Hop Waste Transformation Into Novel Product Assortments for Packaging and Horticulture Sector. Biothop.

14. Liu, Y., Zhang, J., Tang, Y., He, Y., Li, Y., You, J., Breider, F., Tao, S.and Liu, W., 2021. Effects of anthropogenic discharge and hydraulic deposition on the distribution and accumulation of microplastics in surface sediments of a typical seagoing river: The Haihe River. Journal of Hazardous Materials, 404, p.124180.

15. Xu, G., Liu, Y. and Yu, Y., 2021. Effects of polystyrene microplastics on uptake and toxicity of phenanthrene in soybean. Science of the Total Environment, 783, 147016.

16. Blasing, M. and Amelung, W., 2018. Plastics in soil: Analytical methods and possible sources. Science of the Total Environment, 612, pp.422-435

17. de Souza Machado, A.A., Lau, C.W., Kloas, W., Bergmann, J., Bachelier, J.B., Faltin, E., Becker, R., Gorlich, A.S. and Rillig, M.C., 2019

18. Liu, M., Lu, S., Song, Y., Lei, L., Hu, J., Lv, W., Zhou, W., Cao, C., Shi, H., Yang, X. and He, D., 2018. Microplastic and mesoplastic pollution in farmland soils in suburbs of Shanghai, China. Environmental Pollution, 242, pp.855-862.

19. Rillig, M.C., 2018. Microplastics disguising as soil carbon storage. Environmental Science & Technology, 52, pp.6079-6080.

20. Ibrahim, Y.S., Tuan Anuar, S., Azmi, A.A., Wan Mohd Khalik, W.M.A., Lehata, S., Hamzah, S.R., Ismail, D., Ma, Z.F., Dzulkarnaen, A., Zakaria, Z., Mustaffa, N., Tuan Sharif, S.E. and Lee, Y.Y., 2021. Detection of microplastics in human colectomy specimens. JGH Open, 5, pp.116- 121.

21. Khalid, N., Aqeel, M. and Noman, A., 2020. Microplastics could be a threat to plants in terrestrial systems directly or indirectly. Environmental Pollution, 267, p.115653.

22. Pignattelli, S., Broccoli, A. and Renzi, M., 2020. Physiological responses of garden cress (Lepidium sativum) to different types of microplastics. Science of the Total Environment, 727, p.138609.

23. Silva, G., Madrid, F.G., Hernández, D., Pincheira, G., Peralta, A., Gavilán, M.U., Vergara- Carmona, V. and Fuentes-Peñailillo, F., 2021. Microplastics and their effect on horticultural crops: Food safety and plant stress. Agronomy, 11, pp.1528.

24. Bouaicha, O., Mimmo, T., Tiziani, R., Praeg, N., Polidori, C., Lucini, L., Vigani, G., Terzano, R., Sanchez-Hernandez, J.C., Illmer, P. et al., 2022. Microplastics make their way into the soil and rhizosphere: A review of the ecological consequences. Rhizosphere, 22, p.100542

25. Lian, J., Liu, W., Meng, L., Wu, J., Chao, L., Zeb, A., et al. (2021). Foliar-applied polystyrene nano plastics (PSNPs) reduce the growth and nutritional quality of lettuce (Lactuca sativa L.). Environ. Pollut. 280, 116978

26. Yang, J., Li, R., Zhou, Q., Li, L., Li, Y., Tu, C., . (2021a). Abundance and morphology of microplastics in an agricultural soil following long-term repeated application of pig manure. Environ. Pollut. 272, 116028

27. Khorobrykh, S., Havurinne, V., Mattila, H., Tyystjärvi, E. (2020). Oxygen and ROS in photosynthesis. Plants 9, 91.