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Impact of emerging pollutant-Microplastics on Mycorrhizal Symbiosis and Soil Ecosystem Functioning

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Microplastics are considered as an emerging pollutant which causes severe effects in soil, crops and its production is increasing due to generation of plastics from natural or anthropogenic activities. Microplastics (MPs) are formed from break down of larger particles under action of different physical, chemical or biological factors. They are very small in size ranging from 1µm to 5mm having more stability, inert nature and other toxic pollutants can easily adhere to its surface (Bhavsar et al.,2024). They are categorised as primary MPs and secondary MPs based on their origin and sources. The sources of MPs in soil are due to agricultural practices like mulching, agrochemicals, atmospheric deposition, effluents from textiles, fertilizers industries, road dust etc. The MPs are categorised based on their polymer composition like polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polystyrene (PS), polycarbonate (PC) etc. (Dhiman et al.,2024). MPs cause dispersion of soil aggregates and disrupt the soil structure which can lead to decrease in nutrient and water retentive capacity. It effects the different soil micro-organisms, flora and fauna by impeding their growth (Dhiman et al.,2024).

Rhizosphere is the region in soil with plants roots and where presence of beneficial micro-organisms is there. These organisms benefit the plant in their growth by enhancing nutrient cycling, supplying growth hormones. Their lies an interaction between plant roots and the microbes in rhizosphere which is termed as mycorrhiza. It is the association of roots and fungi so that both get benefited. The mycorrhizal symbiosis plays an important role in water uptake, nutrient cycling promoted by extensive hyphal network and in turn the plants give compounds from photosynthesis which supports the fungal metabolism. The symbiosis promotes soil structure, manage plant from stress conditions and thus overall cause benefit to soil and plant. There are several reports that MPs abundance in soil have a negative impact in the mycorrhizal symbiosis and thus interfere the positive effects caused by the symbiosis. Understanding the interaction of microplastics with mycorrhiza is utmost importance for normal functioning of soil which can promote plant growth and development.

Formation of mycorrhiza and symbiosis

The formation of mycorrhizal symbiosis is depicted in figure 1 through flowchart highlighting different steps of formation. There are two types of association between fungi and plant roots. These are arbuscular endomycorrhiza and ectomycorrhiza. In endomycorrhiza, the hyphal network penetrates inside the cortical cells of the plant's root and form arbuscles (branched structure) which act as a site of nutrient and carbon exchange and vesicles (oval structure) acting as an energy reservoir. In ectomycorrhizal association, the fungal network doesn't penetrate inside the cortical cells instead they form Hartig net through which exchange of nutrients and carbon happens.

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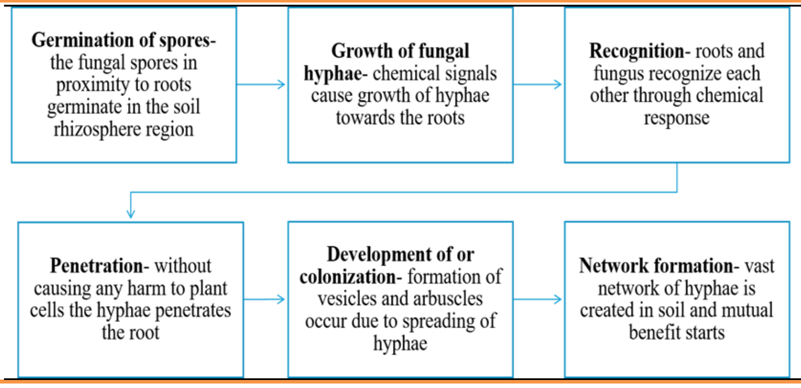

Figure 1: Step by step representation of establishment of fungi in the plant roots and soil

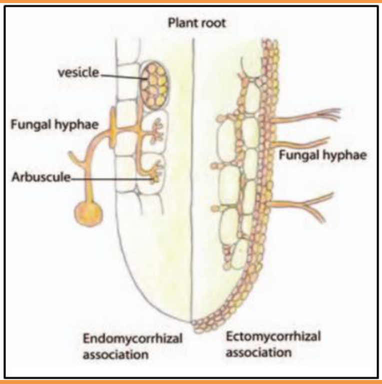

Figure 2: Mycorrhiza and plant root association (Source: Barman et al.,2016)

Impact of microplastics on mycorrhizal symbiosis

Microplastics (MPs) show negative result on mycorrhiza as it interferes with the growth and development of mycorrhizal symbiosis. Accumulation of MPs in soil disrupts the physical, chemical and biological properties of soil. it can reduce the growth of hyphae by lowering soil bulk density, porosity and water or nutrient holding capacity. As a result, the growth of hyphae network ceases. It lowers aggregate stability of soil and thus retentive capacity of soil decreases. All these changes effect the formation of arbuscles and vesicles which is the primary site for nutrient exchange and thus cuts of the bonding of fungi with roots. MPs create damage to fungal metabolism by creating oxidative stress from different toxic chemical secretion.

Arbuscular Mycorrhizal Fungi (AMF) is affected by small size microplastic particles than large size particles because small size have more surface area. Gamage et al.,2025 studied effect of polyethylene MP effect on fungi and rhizosphere region. The result showed that impact of MPs reduces colonization of fungi, spore formation which was created by small, irregular MPs having more ratio of area-volume and the ratio allows them to interact with microbial communities. Thus, they concluded, MPs presence reduces symbiosis and cause reduced growth. Weerasinghe et al.,2022 studied impact of MPs in tomato plants by incorporating two types of MPs and it was clear that the vegetative growth of plants reduced. AMF spore count also reduced due to the negative impact of MPs. There was a study conducted on AMF fungi effect on three different types of MPs- PP, PET, PS (Li et al.,2025). Li et al.,2025 did experiment on lettuce plants and studied the uptake of MPs. The AMF can able to reduce PET uptake by fixing them in soil while no or negative impact on PP and PS. So, AMF worked on reducing harmful effect on specific type of MP. Moreno-Jiménez et al.,2022 found out negative effect of MP on K, Mg, S and increasing availability of Zn in plants. Application of AMF can boost Mn availability in onion. Chen et al.,2026 studied *Lactarius deliciosus* fungi effect on different types of MPs and studied K mobilization in soil. Lammel et al.,2025 did experiment on 3 soils- Haplic Chernozem, Haplic Luvisol and Albic Luvisol. Ten types of MPs were takem to see changes in soils using different genus of AMF and it was seen the MPs of various types and shapes disrupts the soil structure.

Methods to study AMF and MPs interactions

In order to know the impact of MPs and its effects, there is a need to do proper experimental set up which can study MPs and AMF interactions effectively. There are different methods which can easily study the interactions and these are pot experiments, field experiments, greenhouse experiment, spore density measurement, glomalin-related soil protein (GRSP), soil enzymes assessment, MPs analysis using microscope and spectroscopic techniques and different molecular tools like Polymerase Chain Reaction (PCR), Quantitative Polymerase Chain Reaction (qPCR), Internal Transcribed Spacer (ITS sequencing), etc. The pot and green house experiments are usually done to study influence of different types, sizes and shapes of MPs in mycorrhizal development, colonization process and hyphal network formation. MPs are analysed under microscope by staining in dyes and confirm their presence, after which polymeric characterization is done using spectroscopic techniques like Fourier Transform Infrared Spectroscopy (FTIR), Attenuated Total Reflectance (ATR)-FTIR and Raman or Micro Raman instrument. GRSP is done using citrate extraction process to study impact of MPs in soil aggregate. Different molecular techniques help to study the soil microbial communities and biological phenomenon are analysed using enzymes like dehydrogenase, urease, phosphatase etc.

Table 01: Different methods used to study the interactions of AMF and MPs under different soil conditions.

Experimental procedure	Interpretation of the study	References
Factorial experimental design was made by taking 14 treatments and 4 replications consisting of 4 different doses of 2 types of MPs on 2 concentrations of Cadmium in Zea mays	There was a negative effect of MPs in plant's performance with increase in dose of MPs. There was reduction in AMF colonization with MP dose and types	Wang et al.,2020
In onion crops, pot experiment was done in greenhouse condition having controlled temperature and relative humidity. MPs and AMF added to see uptake of macro-micro nutrients in soil and shoots of onion plants kept for 50 days	Plastic fibers showed negative effect in availability and uptake of different nutrients. It lowered K, Mg, S while Zn in soil increased.	Moreno-Jiménez et al.,2022
66 pots were set up in Randomized Complete Block Design (RCBD) with tomato plants. Fiber and film shape of MPs were added in different concentrations. AMF spore counted using decanting and wet sieving methods.	The result showed reduced vegetative growth of crops with increasing concentration of MPs. It showed lesser AMF spore count with increasing amount of MP in pots. Thus, plant's height growth reduced with lesser chlorophyll content and shoot: root ratio was declined.	Weerasinghe et al.,2022
Experimental designs with 6 treatments of 3 MPs-PET, PP, PS were added in lettuce plants with AMF inoculation. Blank and added MPs were treated for effect in plant growth.	It showed increased uptake of PP and PS while decrease in PET as a effect of AMF.	Li et al.,2025
Controlled pot experiment was conducted to see GRSP, Soil organic carbon (SOC) and AMF levels using biodegradable and non-biodegradable MPs	The results concluded like biodegradable MP increases glomalin and SOC. Disruption of structure of AMF occurred through the experiment	Ning et al.,2025

Conclusion

The MPs is having negative effect on microbial communities. It lowers the formation of arbuscles and vesicles as a result decreases the symbiotic activities of mycorrhiza. The effect of MP on AMF symbiosis is guided by the concentration of MPs, type, shape and sizes of MPs. It causes changes in soil physical and chemical properties first and then invade the metabolism of microbes present within the rhizosphere region. It blocks the formation of colonies through growth of hyphal network and cuts off supply of essentials from plants to fungi. Seeing the drastic effect of MPs in soil and plant here lies the greatest responsibility and showing genuine concern to introduce efficient removal techniques and lower the harmful effects. Different remediation techniques through various modern tools should be implemented for proper functioning of soil ecosystem.

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