The role of mycorrhizal associations in plant health and soil ecology

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Abstract. Mycorrhizal associations, a critical symbiosis between fungi and plant roots, play a crucial role in plant health, nutrient acquisition, and soil ecology. This essay examines the different types of mycorrhizal associations, particularly arbuscular and ectomycorrhizal fungi, and their significant contributions to plant nutrition, especially in phosphorus uptake. The symbiotic relationships enhance plant resilience to environmental stresses, such as drought and pathogen attack, by improving water and nutrient uptake and inducing plant defense mechanisms. Furthermore, mycorrhizal fungi contribute to soil structure and nutrient cycling, influencing soil aggregation and carbon sequestration. These interactions have profound implications for sustainable agriculture, offering potential solutions for enhancing crop yields and soil health, while reducing the reliance on chemical fertilizers. Understanding and harnessing mycorrhizal associations can play a pivotal role in addressing challenges related to food security, soil degradation, and climate change.

Key Words: drought resistance, mycorrhizal associations, nutrient cycling, phosphorus uptake, plant nutrition, soil ecology, sustainable agriculture.

Introduction. Mycorrhizal associations represent a fundamental symbiotic relationship between fungi and plant roots, playing a crucial role in plant health, nutrient cycling, and soil structure. These partnerships, which involve over 90% of terrestrial plant species, are essential for the uptake of water and nutrients, particularly phosphorus, and are integral to the resilience of ecosystems. This work delves into the types of mycorrhizal associations, their physiological benefits to plants, their influence on soil ecology, and their potential applications in sustainable agriculture.

Types of Mycorrhizal Associations. There are several types of mycorrhizal associations, the most common being arbuscular mycorrhizal fungi (AMF) and ectomycorrhizal fungi (EMF) (Ferlian et al 2021) (Figure 1). AMF are characterized by the formation of arbuscules within the root cells, which facilitate nutrient exchange between the fungus and the host plant. They are prevalent among herbaceous plants, including most agricultural crops (Ksentini et al 2020).

EMF, on the other hand, form a sheath around the root tips and are more common in woody plants, such as trees and shrubs (Dreischhoff et al 2020). Unlike AMF, EMF do not penetrate root cells, but instead create a network around them, known as the Hartig net, through which nutrient exchange occurs (Kumar et al 2022). Other types include ericoid mycorrhizae, found in heathland plants, and orchid mycorrhizae, which are essential for the germination and growth of orchids.

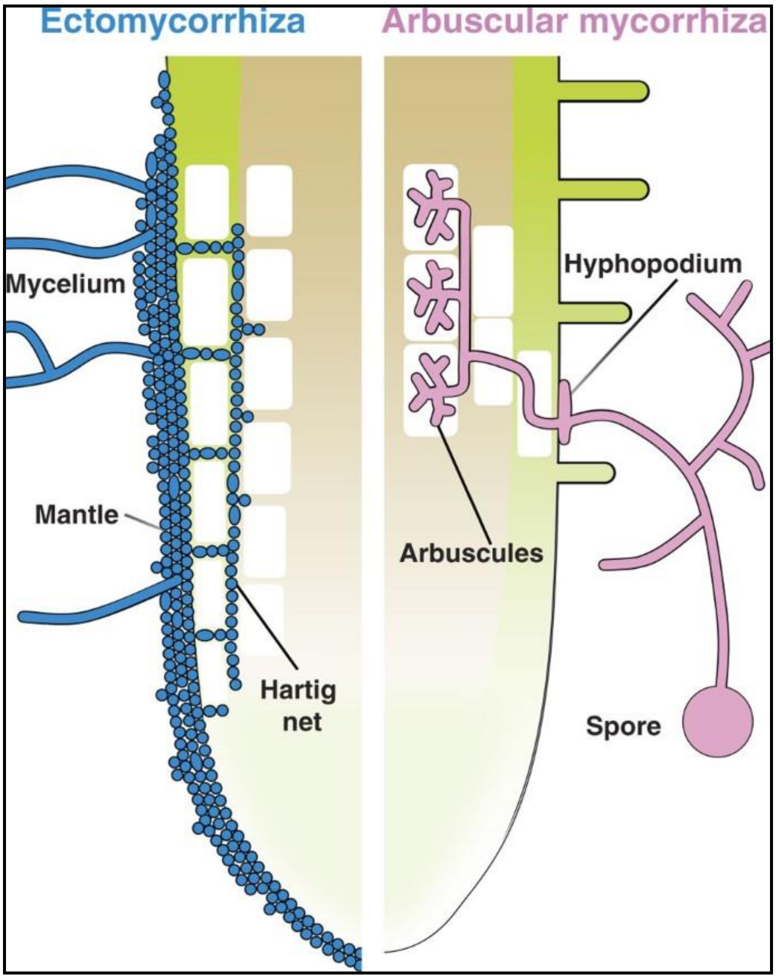

Figure 1. The ectomycorrhizal fungus surrounds the root tip with a thick mantle of closely appressed hyphae, whereas the Hartig net develops around epidermal cells (green) (Bonfante & Genre 2010). In the case of arbuscular mycorrhizas, the root tip is usually not colonized. Hyphae develop from a spore and produce a hyphopodium on the root epidermis. Intraradical colonization proceeds both intra and intercellularly and culminates with the formation of arbuscules, little fungal trees, inside inner cortical cells (brown) (source: Bonfante & Genre 2010).

Nutritional Benefits to Plants. Mycorrhizal fungi significantly enhance plant nutrition by extending the root system's reach through their hyphal networks, which can access nutrients beyond the depletion zone of the plant roots. One of the most critical nutrients provided by mycorrhizae is phosphorus, which is often limited in soils. Mycorrhizal fungi can solubilize phosphate compounds in the soil, making phosphorus more available to plants (Etesami et al 2021). This is particularly beneficial in soils with low phosphorus availability, such as those with high pH or in tropical regions with highly weathered soils.

In addition to phosphorus, mycorrhizal fungi can also facilitate the uptake of other essential nutrients, including nitrogen, potassium, calcium, and trace elements such as zinc and copper (Dhalaria et al 2020; Khaliq et al 2022). This nutrient transfer is facilitated by the production of organic acids and enzymes by the fungi, which help to mobilize nutrients from the soil matrix.

Enhanced Plant Resilience. Beyond nutrient uptake, mycorrhizal associations enhance plant resilience to various environmental stresses. One of the most well-documented benefits is improved water uptake, particularly in arid environments. The extensive hyphal network of mycorrhizal fungi can access water in soil micropores that plant roots alone cannot reach, thus improving the water status of the host plant and increasing drought resistance.

Furthermore, mycorrhizal fungi contribute to plant health by enhancing resistance to soil-borne pathogens (Kalamulla et al 2022). This protective effect is partly due to competition for resources between mycorrhizal fungi and pathogenic microbes and the induction of plant defense mechanisms. Mycorrhizal plants often exhibit increased levels of defensive compounds, such as phenolics and pathogenesis-related proteins, which help protect against diseases.

Impact on Soil Ecology. Mycorrhizal fungi play a vital role in soil ecology by influencing soil structure and nutrient cycling. The fungal hyphae contribute to soil aggregation by physically binding soil particles and producing extracellular polysaccharides, which act as a glue to stabilize soil aggregates. This improved soil structure enhances soil aeration, water retention, and root penetration, creating a more favorable environment for plant growth.

In terms of nutrient cycling, mycorrhizal fungi contribute to the decomposition of organic matter and the recycling of nutrients (Tunlid et al 2022). Through their interactions with other soil microorganisms, mycorrhizal fungi influence the microbial community composition and activity, further affecting nutrient availability in the soil. They are also involved in the sequestration of carbon in soils (Petrescu-Mag et al 2023), as the hyphal networks contribute to the stabilization of organic carbon in soil aggregates, thus playing a role in mitigating climate change.

Applications in Sustainable Agriculture. The benefits of mycorrhizal associations extend to sustainable agriculture, where they can be harnessed to enhance crop yields and reduce the need for chemical fertilizers. Inoculation of crops with mycorrhizal fungi, known as mycorrhization, can improve nutrient use efficiency, particularly phosphorus, reducing the reliance on synthetic fertilizers. This not only lowers production costs but also mitigates the environmental impact of fertilizer runoff, which can lead to eutrophication of water bodies.

Additionally, the use of mycorrhizal fungi in agriculture can improve soil health and structure, leading to more resilient cropping systems. This is particularly important in the face of climate change, as mycorrhizal associations can enhance crop tolerance to abiotic stresses such as drought and soil salinity.

Conclusions. Mycorrhizal associations are a cornerstone of plant health and soil ecology, providing essential nutrients, enhancing resilience to environmental stresses, and contributing to soil structure and fertility. Their integration into agricultural practices offers a pathway to more sustainable and resilient food production systems. As research continues to uncover the complex interactions between mycorrhizal fungi, plants, and soil, there is immense potential to harness these relationships to address global challenges such as food security, soil degradation, and climate change.

Conflict of Interest. The authors declare that there is no conflict of interest.

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Received: 28 October 2023. Accepted: 29 November 2023. Published online: 30 December 2023.
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How to cite this article:
Papuc T., Bora F. D., 2023 The role of mycorrhizal associations in plant health and soil ecology. AAB Bioflux 15(2):140-143.