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Trees and Mycorrhizal Fungi – A Remarkable Alliance

Trees and fungi interact in complex ways. Sometimes, the two groups of organisms would even find it hard to survive without each other.

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The term "symbiosis" is used in biology to describe a close relationship between at least two organisms of different species. One special example of such an interdependence is called "mycorrhiza" – a remarkable symbiotic association between plant roots (autotrophs) and fungi (heterotrophs). Mycorrhizal symbiosis is one of the most fascinating ways in which plants adapt to life on land.

Plants, being primary producers, absorb carbon and provide shelter and food for countless other organisms. Forest communities are dominated by woody plant species. Despite their size and longevity, such plants live not independently but in association with a wide variety of microorganisms. These include fungi, which play a role of special importance. While pathogenic fungus species may pose a threat to trees, a large group of other fungi actually have beneficial effects for the health and life of woody plants. These include saprotrophic fungi, which decompose dead organic matter and release nutrients that can be absorbed by plant roots, as well as mycorrhizal fungi, which live in close symbiosis with plants. This alliance between trees and fungi has a very long evolutionary history. Evidence suggests that plants first displayed the ability to form symbiotic relationships with fungi more than 450 million years ago, and the emergence of symbiosis between fungi and bacteria is linked to the evolution of feeding strategies. The priority role of plant–fungi partnerships seems to be confirmed, for example, by the fact some plant genes actually code for proteins whose purpose is to attract fungi to the soil near their roots.

Types of mycorrhiza

Mycorrhiza, or mycorrhizal symbiosis, is a common phenomenon whereby plant roots form a close anatomical and physiological association with certain non-pathogenic, highly specialized fungi in the soil. Trees in European forests form such mycorrhizal relationships. Some species are "obligately" mycorrhizal (including beech, oak, pine, and spruce) while others are "facultatively" mycorrhizal (such as birch, willow, and alder): the former rely crucially on mycorrhizal symbiosis for their proper growth and development, whereas the latter form such relationships only in certain environmental, mainly soil-related conditions.

The most common type is "external" mycorrhiza, or ectomycorrhiza, which is formed on the smallest tree roots. Its distinctive trait is the formation of what

is called the Hartig net – a complex system of hyphae surrounding the ground cells of the root cortex. Ectomycorrhiza results in the formation of a fungal mantle that envelopes the roots. Another type of symbiosis between plants and fungi is arbuscular mycorrhiza, or endomycorrhiza. This is the "internal" type of mycorrhiza, with the hyphae penetrating the cortical cells and forming characteristic tree-like structures called arbuscules or fungal vesicles. Both types of mycorrhizae can be found, for instance, on the roots of poplar and willow trees.

A single tree species usually has many partner fungal species. In fact, the species of mycorrhizal fungi that form relationships with trees vary depending on the age of the host: different fungi will be found on seedlings, juvenile trees, and old trees of the very same species. This means that as trees age, we can observe the phenomenon of mycorrhizal succession – the species composition of accompanying mycorrhizal fungi changes, and the number of fungi species increases. There are also fungal species that can be found both on young and mature trees throughout their long lives. Some fungi are closely associated with specific tree species. This is a fact well-known to avid mushroom-hunters in Eastern Europe: they know to go looking for slippery jack mushrooms under pine trees, for porcini mushrooms under pine or spruce trees, for *Leccinum* genus mushrooms near aspen, birch, hornbeam, hazel, and pine trees (depending on the fungus species), and for *Xerocomus* mushrooms

This fly agaric (*Amanita muscaria* – a classic „toadstool") like other mushrooms, forms ectomycorrhizae with tree roots under spruce trees. This is because these fungus species are associated with specific plant partners. Others are cosmopolitan species, which means that they can form alliances with many trees.

Quid pro quo

Mycorrhiza can be descried as an "exchange-based partnership" struck up between representatives of two different kingdoms – plants and fungi. Trees provide mycorrhizal fungi with carbohydrates, which are produced by the plants through photosynthesis. In exchange, the fungi offer minerals, hormones, increased absorbent surface area, and the ability to penetrate the soil. By secreting appropriate enzymes into the rhizosphere, fungi activate nutrients contained in organic compounds inaccessible to trees. Fungi supply their plant partners primarily with phosphorus and nitrogen compounds. Fungal hyphae linked to tree roots can reach a lot farther than the tree roots. By penetrating the soil, the mycelium allows the compounds needed by the roots to be transported from distant locations and – together with the compounds secreted by the hyphae – improves soil stabilization, aggregation, structure, and fertility.

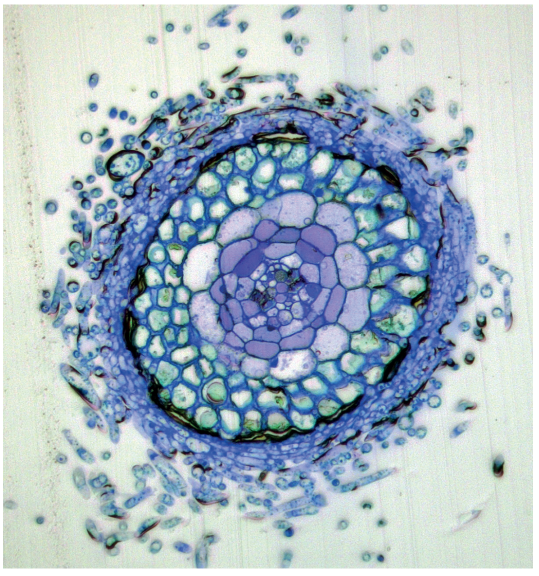
Mycorrhizal fungi also facilitate communication and transport of resources between trees by forming an underground network. The common mycorrhizae network (CMN) is a physical link between plants, formed when the hyphae of mycorrhizal fungi interconnect the underground roots of multiple plants of the same or different species. Scientists have been discovering more and more about how this "underground Internet" allows plants to communicate. Connections formed in this way make it possible to transport sugars, mineral compounds, and water between trees. As such, older, mature trees can support smaller ones, for example those growing in shade. In return for their transport services, the mycelial network "collects a fee" from the connected trees, in the form of about 30% of their photosynthetic products. Interestingly, a study of Douglas firs conducted at the University of Reading in the United Kingdom found that in the transport of carbon compounds, the network distinguishes between root tips belonging to different tree species, favoring certain species and prioritizing them as recipients of carbon compounds and minerals. Underground mycorrhizal networks can also serve as a warning system: the mycelium can be used by the plants to communicate potential threats.

Ectomycorrhizae of a Scotch pine in forest soil

Fungal allies

Abiotic stress factors hamper plant growth and development. Human activity, industrial development, exploitation of raw materials, and the chemicalization of agriculture all contribute to environmental degradation and augment abiotic stress's impact on plants. Trees whose roots are colonized to a greater extent by mycorrhizal fungi cope a lot better in unfavorable soil conditions, on what may be called "harsh" land. In addition to post-agricultural land, harsh land conditions are also found in forests in industrial areas with increased and high concentrations of air, water, and soil pollution, post-industrial wastelands (waste heaps, dumps, open pits) that are recultivated and converted for forestry use, and areas along highways and expressways, both existing ones and those under construction. A special threat is posed by heavy metals – even in small concentrations, they can negatively affect biological processes in the soil and in living organisms.

Fungi, including mycorrhizal fungi, have garnered significant attention as a natural component of the environment with the capacity to mitigate the effects of pollution. Without fungal partners, it is next to impossible for woody plants to grow on degraded post-industrial land, post-agricultural land, and on what may be described as "hard to restore" areas. Ectomycorrhizal fungi, whose spores are carried over long distances by wind, are the first to spread on degraded areas (unlike arbuscular fungi, which form spores below the soil surface). Ectomycorrhizal fungi often form what is called extramatrical mycelium, which helps to improve soil quality. Likewise, they can bind heavy metals in the mycelium and limit their penetration into plant tissues, thus providing an effective method of biofiltration. The fungal mantle surrounding plant roots can act as a filter, too. Moreover, mycorrhizal fungi have the ability to break down various chemical



Cross-section of the mycorrhizal root of a sessile oak tree, visibly showing fungal mantle surrounding the root

compounds and produce enzymes that reduce stress, resulting from the excess of free radicals.

The positive impact of mycorrhizae involves not only removing heavy metals from the soil in difficult areas, but above all increasing yield weight, improving soil conditions, and protecting plants from pathogens. Fungal species vary in terms of how effectively they can protect trees in degraded, contaminated areas, or their ability to detoxify and accumulate heavy metals, effectively stimulate tree growth, and offer protection against pathogens. For this reason, the use of selected strains of mycorrhizal fungi to inoculate tree seedlings to be planted on contaminated land can play an important role in facilitating the reforestation of difficult habitats, and improving the soil structure and increasing the amount of organic matter create conditions for the development of other plants. This makes it significantly easier for forests to be successfully grown even on land that is not well-adapted to this. Seedlings inoculated with mycorrhizal fungi have also been shown to be more resilient and adapt better to harsh conditions.

Safe ecosystems

Mycorrhizal associations allow water and nutrients to be transported through the mycelium from areas normally inaccessible to plant roots themselves. This process benefits the plant and improves the survival of young trees in drought conditions. Water deficiencies in the soil reduce the intensity of physiological processes in plants, including photosynthesis, nutrient uptake and transport, and hormonal balance. Physiological disturbances also trigger osmotic and oxidative stress. Strategies for coping with drought stress include interacting with mycorrhizal fungi, which support trees through various mechanisms, including by increasing the absorption surface area of the root system in the soil through the development of the extramatrical mycelium and its branches.

Fungi can also act as a physical barrier by making it difficult for other organisms to damage the roots. The fungal mantle acts as a kind of "armor" for the delicate, fine roots, which boosts and secures their effective absorption of water. Mycorrhizal fungi compete with pathogenic species for the same ecological niche and food resources. By producing secondary metabolites, such as antibiotics, and by stimulating the plant to produce phenolic compounds, mycorrhizal fungi help curb the growth and development of these other fungi in the soil that can impact negatively on plants. By forming mycorrhizal associations, plants can gradually improve their own health and become less susceptible to infections by pathogenic fungi such as *Heterobasidion annosum* (causing a disease called annosus root rot) and various species of the genus *Armillaria*. This makes it possible to preserve the proper proportions between the various elements of the soil environment.

> By forming close associations with certain fungi, plants are better able to cope with the increasing threats of climate change.

Various types of environmental stress are becoming further compounded by ongoing climate change. By forming associations with such microorganisms as chiefly fungi and bacteria, plants are better able to cope with the attendant dangers, such as rising temperatures, increased concentrations of carbon dioxide in the atmosphere, drought, fires, nitrogen deposition, soil salinization, high levels of heavy metals, changing soil pH, air pollution, and excessive pesticide concentrations. This makes it all the more important for us to search for fungal allies that are better adapted to changing environmental conditions. Various species of fungi that form mycorrhizae affect tree physiology in various ways. Although the research literature contains some reports describing negative or no effects of mycorrhizae in response to stresses, such as drought, there are far more studies that reveal the favorable impact of mycorrhizal symbiosis on plants. The interaction between trees and mycorrhizal fungi is extremely important for mitigating the effects of climate change, which will translate into the presence of more stable and secure forest ecosystems. ■

Further reading:

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