Mycorrhizal Fungi in Northeastern Forest Ecosystems

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What are mycorrhizal fungi and why are they important in forest ecosystems?

1. Approximately 90% of all plants associate with some kind of mycorrhizal fungi! Mycorrhizal fungi have evolved to live in or on tree roots and get their food (carbon) from plants rather than getting carbon from decomposing organic matter in the soil like some other types of fungi. Much like plants have roots, fungi have hyphae that are very fine and are able to scavenge or mine (break down organic matter) for soil nutrients which are too difficult for plant roots to access.

2. Mycorrhizal fungi have been found to reduce drought stress, protect roots from soil pathogens, and increase soil permeability which indirectly aids water flow to roots.[1,2] However, the most important reason plants allow mycorrhizal fungi to live with their roots is increased access to nutrients necessary for plant growth and reproduction, such as nitrogen and phosphorus.[3] In exchange for these nutrients, plants transfer sugars or amino acids as exudates through their roots to the fungal hyphae — and this is the fungi's source of carbon for energy and growth.[4]

3. Two main types of mycorrhizal fungi are arbuscular (AM) and ectomycorrhizal (EcM) fungi and they form associations with roots in different species of trees. Most trees are associated with only one type of mycorrhizal fungi, but a few species of trees (including poplar and willow) can associate with both.[5] EcM fungi grow on the outside of the root cells and form a structure called the hartig net which encases the root tip. Trees and fungi exchange nutrients in the space between the root tip and the hartig net. AM fungi grow into the tree's root in between the cell wall and membrane. They grow structures called arbuscules which provide the space for resource exchange.[6]

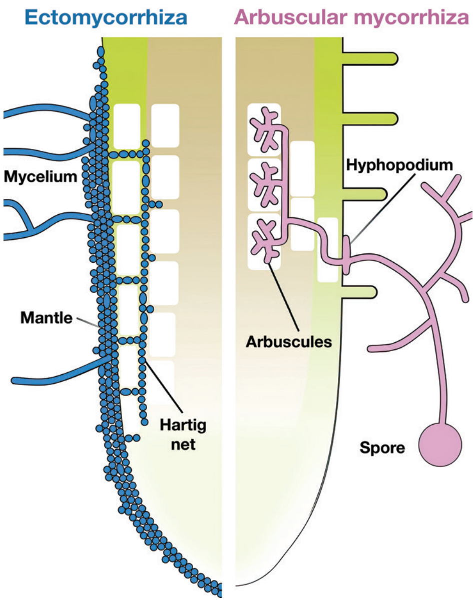

Figure 1: Arbuscular and ectomycorrhizal root systems *(Glass, et al. 2004)*

Figure 2: Arbuscular mycorrhizal (AM) and ectomycorrhizal (EcM) fungi

(Left: Marthinus Jacob Rossouw at SANBI. Right: Mycorrhizae — The Symbiotic Relationship between Fungi and Roots. (2022, June 8). Boundless. https://bio.libretexts.org/@go/page/13792)

Trees in Northeast Hardwood Forests and Their Mycorrhizal Associations

HARDWOOD SPECIES		
Tree Species	**Common Name**	**Mychorrhizal Association**
Fraxinus nigra	Black ash	Arbuscular
Fraxinus pennsylvanica	Green ash	Arbuscular
Fraxinus americana	White ash	Ecto/Arbuscular
Populous grandidentata	Bigtooth aspen	Ecto/Arbuscular
Populous tremuloides	Quaking aspen	Ectomycorrhizal
Tilia americana	American basswood	Ectomycorrhizal
Fagus grandifolia	American beech	Ectomycorrhizal
Betula alleghaniensis	Yellow birch	Ectomycorrhizal
Betula lenta	Black birch	Ectomycorrhizal
Betula papyrifera	Paper birch	Ectomycorrhizal
Prunus serotina	Black cherry	Arbuscular
Nyssa sylvatica	Black gum	Arbuscular
Carya cordiformis	Bitternut hickory	Ectomycorrhizal
Ostrya virginiana	American hophornbeam	Ectomycorrhizal
Acer rubrum	Red maple	Arbuscular
Acer pensylvanicum	Striped maple	Arbuscular
Acer saccharum	Sugar maple	Arbuscular
Quercus rubra	Northern red oak	Ectomycorrhizal
Quercus alba	White oak	Ectomycorrhizal

SOFTWOOD SPECIES		
Tree Species	**Common Name**	**Mychorrhizal Association**
Thuja occidentalis	Northern white-cedar	Arbuscular
Abies balsamea	Balsam fir	Ectomycorrhizal
Pinus strobus	Eastern white pine	Ectomycorrhizal
Tsuga canadensis	Eastern hemlock	Ectomycorrhizal
Picea rubens	Red spruce	Ectomycorrhizal

How do ectomycorrhizal and arbuscular mycorrhizal fungi differ?

1. Trees associated with EcM and AM fungi in temperate forests are associated with patterns of leaf litter quality. Litter quality describes how easy it is for microbes to break down or decompose the leaf after it senesces. EcM-associated trees, such as pine and hemlock, often have lower quality litter that takes longer for microbes to decompose, while AM-associated trees, such as ash and sugar maple, generally have leaf litter that decomposes quickly. These differences can affect how nutrients are cycled in the soil.[7] However, there are exceptions. Some EcM-associated trees, such as basswood and birch, have relatively high litter quality, and some AM-associated trees, such as northern white cedar, have relatively low litter quality.

2. Trees and their associated mycorrhizal fungi "feed" soil microbes to encourage them to decompose organic matter and release nutrients that the trees need.[8] The mycorrhizal fungi pass sugars supplied by the trees to fungi and bacteria in the soil.[9] These sugars, along with other bits of organic matter such as fungal hyphae and fine roots, make up a collective of belowground inputs called rhizodeposits.[10]

3. EcM fungi are more diverse than AM fungi, and their diversity in species reflects a wide range of growth forms from short, long and dense-mat like forms. AM hyphae grow only short distances from the tree's root tips. The greater amount of hyphal tissue of EcM fungi means that more dead fungal tissue is available for other microbes to feed on.[11]

4. AM and EcM fungi access nutrients differently. AM fungi must scavenge nutrients which have already been released in the soil from decomposing organic matter. Many EcM fungi can produce enzymes that actively decompose organic matter to "mine" nutrients, such as nitrogen and phosphorus, for themselves and their plant hosts.[12,13] The enzymes produced by EcM fungi are similar to enzymes in our bodies — they break down organic molecules into smaller molecules that the fungi can absorb back into their tissue that then travel to plant root tips.

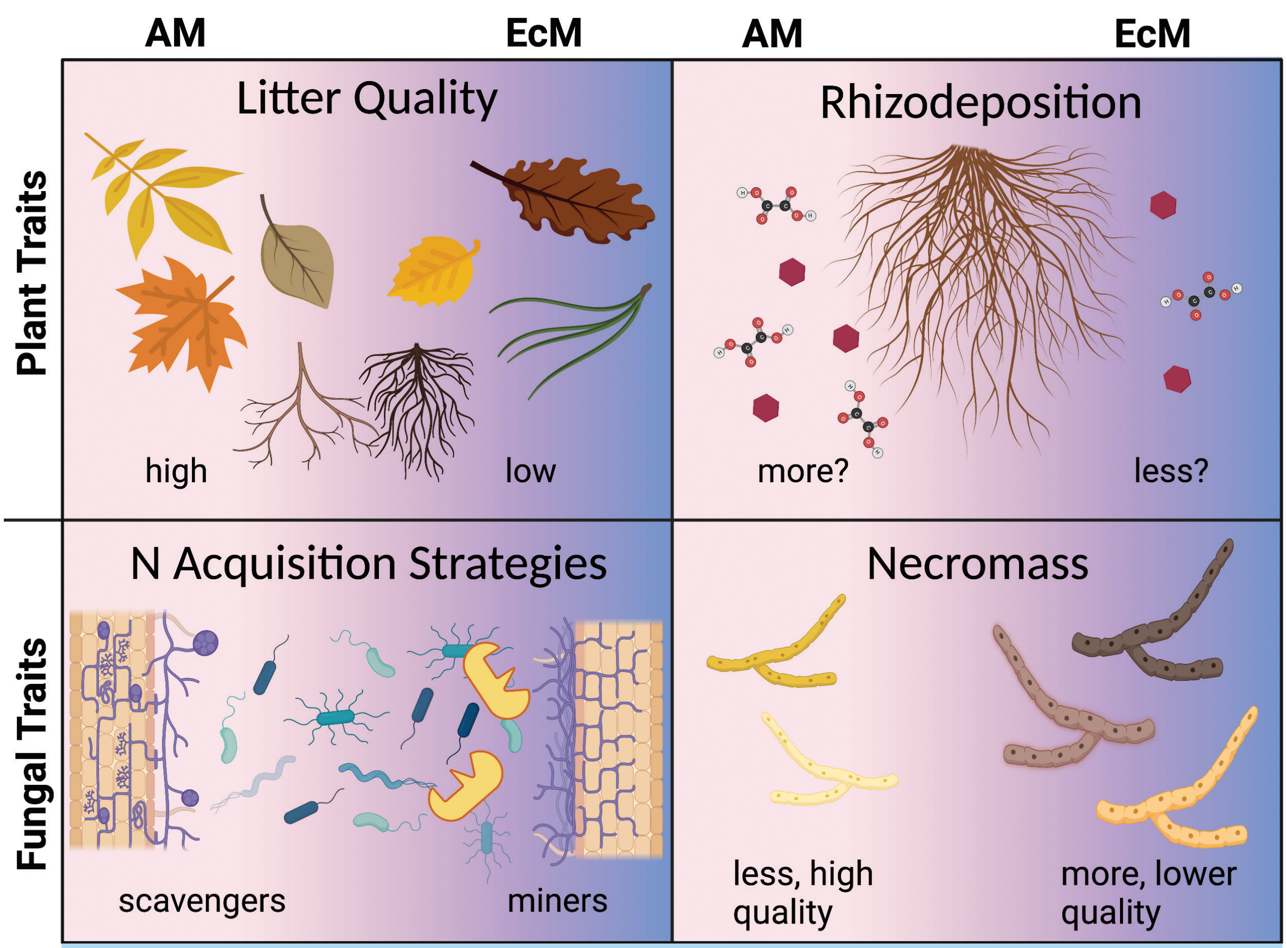

Figure 3: Differences between arbuscular (AM) and ectomycorrhizal (EcM) mycorrhizal fungi *(Caitlin Hicks Pries using Biorender.com)*

Why is it important to know more about the relationships between mycorrhizal fungi and trees in Northeastern forests?

1. Across temperate forests, Northeastern forests have a high diversity of tree families compared to forests in places like the Pacific northwest, where much of the mycorrhizae-forestry research has been conducted. While many Northeastern forests are EcM-dominated, there is still substantial biomass of AM trees and the understory plants are usually AM-associated.
2. Climate change may affect the distribution of tree species in the Northeast[14], but these changes may differ by the type of fungal association. One study found that AM-associated trees are better suited to warmer environments and are projected to migrate northward.[15]
3. Invasive insects complicate the regional effects of climate change: The introduction of the emerald ash borer will likely reduce white ash, an important AM-associating tree. The hemlock woolly adelgid is another invasive insect that could harm eastern hemlock populations.[16,17] Depending on the severity of outbreak and the tree species that fill the spaces that ash or hemlock leave behind, the ratio of AM to EcM-associated trees in Northeastern forests could change drastically.
4. Some studies have found that EcM fungi may provide stronger protection against soil pathogens, allowing EcM-seedlings to grow closer to trees of the same species compared to AM seedlings.[18]
5. Common mycorrhizal networks (CMNs), which are connections of fungal hyphae between roots of different trees, could act as a buffer against environmental stresses like drought. There is some evidence that water and other resources can be transferred between these networks.[19] Because EcM fungi grow longer and more extensive hyphal networks than AM fungi, they may provide more robust CMNs to facilitate resource transfer under drought conditions or after disturbance. Longer or more extensive EcM CMNs could potentially span gaps of harvested or downed trees, connecting trees at further distances than AM CMNs. One study suggests that CMNs also allow EcM-associated seedlings to overcome any negative effects of being in close proximity to the same species.[20]
6. There is still debate about which type of mycorrhiza creates more rhizodeposits and how different conditions change their inputs. For example, some species of trees, such as AM-associated maples, may decrease fine root growth under drought stress.[21]

What do we know so far about how mycorrhizal fungi interact with forest management in the northeast?

1. Forest harvesting may lead to initial declines in the abundance and diversity of ectomycorrhizal fungi depending on the size of the harvested gap. In one study conducted in New Hampshire, EcM fungal fruiting bodies (mushrooms) declined after harvesting compared to unharvested forest areas.[22] The gap sizes of nearly one acre in this experiment were large enough to reduce a critical number of trees contributing sugars to the CMN in a concentrated area. A future study exploring how differences in gap size affect fungal fruiting bodies could help us to understand how resilient CMNs are across gap sizes.
2. After forest harvesting, mycorrhizal fungal communities can recover, and one of the factors affecting time to recovery is dispersal of fungal spores. Rodents are key players in dispersing mushroom spores from forested areas to gap cuts, helping with the recovery of mycorrhizal fungi abundance and diversity following harvesting. However, a study from northern New Hampshire showed that multiple rodent species disperse spores of AM fungi, while only one rodent species dispersed EcM spores, making the EcM spore dispersal networks more specialized and vulnerable.[23]

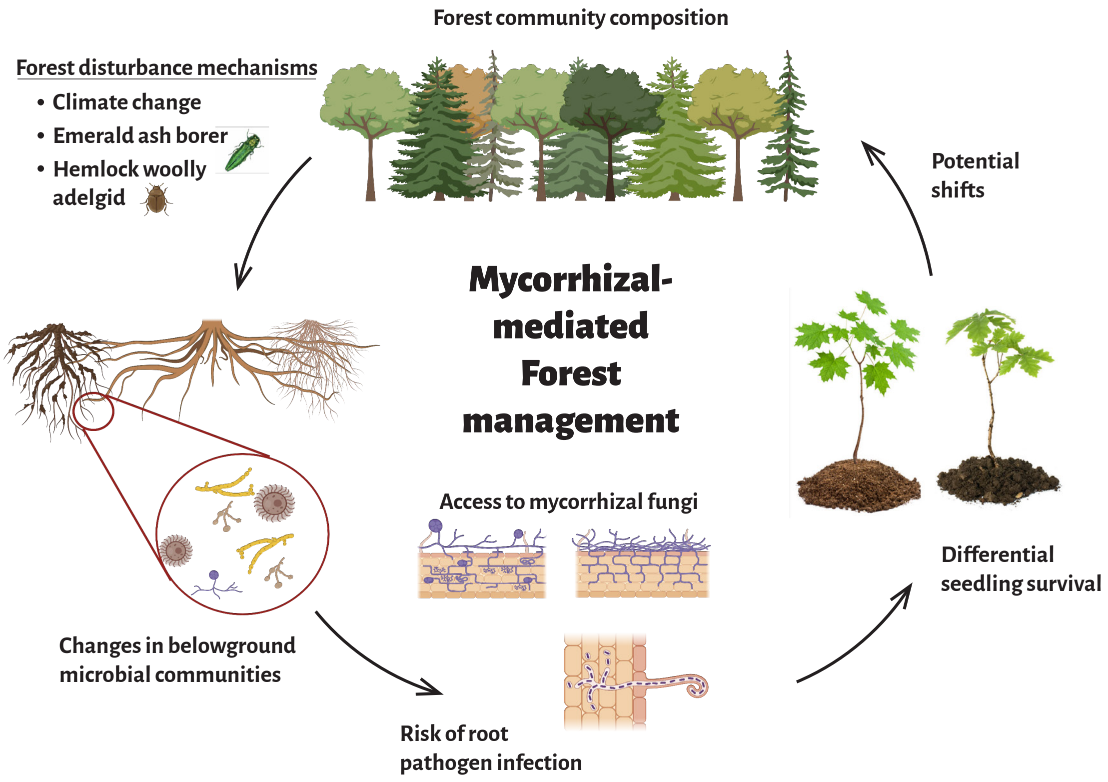

Figure 4: Conceptual model of how tree mycorrhizal fungal associations could affect forest regeneration: Forest disturbances may remove certain tree species, resulting in changes to belowground microbial communities. Depending on the tree species' mycorrhizal association, there may be differences in protection from root pathogens and access to mycorrhizae for colonization. These potential microbial community drivers could lead to differences in seedling survival and forest regeneration. *(Amelia Fitch, using Biorender)*

Ongoing Mycorrhizal Research

Considering the importance of mycorrhizal fungi for forest health and productivity, Caitlin Hicks Pries, Amelia Fitch, and Eva Legge are studying the interaction of different forest harvesting strategies and mycorrhizal associations in a northern hardwood forest near Corinth, Vt. This site is also the location of the Adaptive Silviculture for Emerald Ash Borer co-led by Tony D'Amato (professor, University of Vermont) and Kevin Evans (director of woodlands, Dartmouth College).

The first of two related mycorrhizal fungi projects focuses on quarter-acre forest gaps which were previously dominated by trees associated with either AM or EcM fungi. We are sampling soils and monitoring eight species of planted seedlings (AM-associated: sugar maple, red maple, black gum, black cherry; EcM-associated: black birch, red oak, basswood, bitternut hickory) for survival and growth to answer the questions:

1. Following harvesting, how does soil nutrient cycling and organic matter storage differ between forests dominated by AM- and EcM-associated trees?
2. Does seedling survival and growth differ between forests previously dominated by AM- and EcM-associated trees?

In a second project, we are interested in how thinning versus gap-based regeneration harvests affects three AM-associated seedlings: sugar maple, black cherry and black gum. We planted seedlings in forested areas undergoing both types of management. In both the selectively thinned and the patch cut plots, we planted the seedlings under varying levels of exclusion from the surrounding mycorrhizal network, to see how seedling growth and survival are affected by access to belowground networks under these two management practices.

For posted updates see the Hicks Pries Lab website (https://sites.dartmouth.edu/hicksprieslab/improving-soil-carbon-storage-in-grazed-fields/) and to visualize data see "Let's Talk Trees" (https://jp-gannon.shinyapps.io/S23-EDS-Fungi/) created by students Rasheed Pongnon, Trayda Murakami, and Will Poncy, with their mentor J.P. Gannon at Virginia Tech. ■

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Field Notes:

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