`Mycorrhizae Fungi (Mushrooms) Evolution - Expanding Flora's Range and Soil's Carbon Storage

Version 2025-12-10 3:43 PM Thanks to Elise Bresnik & Dr. David Patriquin (Dalhousie U.). Materials: > NS Wild Flora Society

Mosses and plants, like animals, have various means of accessing water, nitrates, nutrients, carbohydrate energy, pathogen warnings, and biochemical defenses. While humans have water bottles, farmers markets, thermometers, pharmacies, and vehicles to get them there, plants have stomata, roots of various thicknesses, lengths, and capabilities, and the use of mineral rock and soil. Most plants, though, rely on far more than that. Most plants connect with fungi and many cannot live without specific fungi. [1]

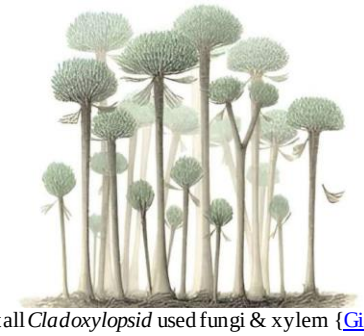
Dr. Suzanne Simard, "It was more efficient for the plant to invest in cultivating the fungi than growing more roots because the fungal walls were thin, lacked cellulose and lignin, and required far less energy to make.">***Using fungi, plants exchanged produced sugar for hard to reach water, nitrogen, and nutrients, even in ancient, acidic, poorer, & drier soils. After the exchange, fungi bonded their carbon residue onto the soil. A Swedish study found 47% to 70% of plant's latest carbohydrates were taken to "deeper levels of the soil."***

Fungi can be generalists. Others have specific duties. Some share carbohydrates or amino acids. Certain fungi forage for specific nutrients, in different places, or only for certain plants. [2]

Earth's million fungi types coevolved with flora & soil. Below are 8 significant events in their coevolution.

[500 MYA (million years ago.**)] ARBUSCULAR FUNGI.** ***AMF penetrate roots' cortical cells***. Visible land life couldn't have surfaced except for special traits & collaborators. W. Rimington & J. Morris report AMF began the coevolution with early liverworts or similar plants, to retrieve nutrients, form soils & secure carbon.[3]





466mya granite moss on dry barren rock. 445mya 2-10 cm flimsy flora used arbuscular {Wikimedia} 390mya tall *Cladoxylopsid* used fungi & xylem {Giesen & Berry}

[466 MYA] MOSSES appeared on Earth's still dry & very barren surface, processing nutrients out of Earth's rock mantle. Mosses retain moisture longer, can hibernate when there is drought, and, as Dr. Tim Lenton (U. of Exeter) found, ancient mosses could weather calcium and magnesium from andesite rock, and iron and phosphorus from granite. These mosses made more soil and brought Earth's atmospheric CO_2 down from between 5460 and 8580 parts per million to levels that caused polar ice caps.

Even when moss is in the shade, moss's chlorophyll has been "fine-tuned to absorb the wave lengths of light that filter through the forest canopy." Currently, moss sucks up carbon dioxide, emits oxygen, holds soil together, keeps soil below its mats cool, moist, and protects that soil's crucial microbes. Besides also cycling nitrogen and phosphorus, keeping pathogens down, and, with many moss hosting nitrogen-fixing bacteria, moss "also acts as a storage pool for nutrients, including carbon, currently keeping about 6.43 billion metric tons of this vital but currently problematic element out of our oversaturated atmosphere." [4]

[~445 MYA] ARBUSCULAR FUNGI. Within thin soils, early bryophytes would be followed by 2-10 cm vascular club moss. AMF continued its evolution and exchange with club moss. The collaboration formed more soil and lowered levels of atmospheric CO_2, and contributed to the significant ice age. Later AMF would serve many fern and all horsetail. ~150 mya, AMF would begin to serve many flowering plants.[5]

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[1] Coevolution: Prof. Tom Wessels (Antioch U.) July 3, 2019 "The Ecology of Coevolved Species" Youtube 35:10 *New England Forests.* At [12:28]

[2] Fungi: Dr. S. Simard (UBC) 2021 Finding the Mother Tree. pp.60,68,80,98,167-170,222-223. Fungi carbon soil storage: B Yirka 2013 "Study finds fungi, not plant matter, responsible for most carbon sequestration in northern forests." *Phys.org*. From K. E. Clemmensen Swedish Univ. of Agri Sci. E. Lacroix Dartmouth College;

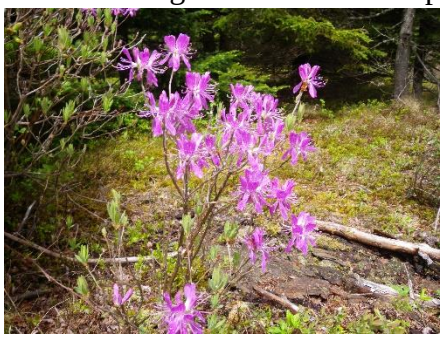
[3] Drought: C. Zhao, Tasmania Inst. of Agri. Immunity: I. Yotsui, Tokyo U. of Agri.; Photosyn.: M. Kanaris U. Toronto; Genome: J. L. Bowman, Monash U.; Fungi connects: PM Delaux U. of Toulouse; M. Smith Durham U.; With liverwort or earliest flora: W. Rimington Imperial College London; E. Pennisi *Science* & J. L. Morris U. of Bristol.

[4] S. Perkins *Science* & T. Radford *The Guardian*. From Dr. T. Lenton (U. Exeter). Dr. R. Kimmerer. (State U. of NY) Gathering Moss 2003 p15, 35-42. T. Koumoundouros 9 May 2023 *Science Alert*. From Dr. D. Eldridge (U. New South Wales) & 50 others 2023 *Nature GeoScience*. Also Oak Ridge National Laboratory sphagnum study

[5] Early soils: Dr. J. McMahon U. Cambridge; Necessary connection: Dr. M. K. Rich U. Toulouse; Fossils of *Eophytes*: Dr. D. Edwards Cardiff U.;

[407-365 MYA] XYLEM TO WOOD. Notable change was evolution of flora's water-conveying xylem to lignin & wood, allowing mid-Devonian 30 m trees to stay anchored & hydrated. ***Saprophyte fungi, also evolved to break down tree's cellulose and lignin. The fungi left recovered carbon & nutrients in soil ecosystems.*** Soil CO_2 emissions were controlled by lichen, moss, plant litter, or coal-forming tectonics & swamps.[6]





Deadwood served by saprophytes, lichen, & moss. 156 mya pine and birch began use of Ectomycorrhizae. 140 mya Heath family began use of Ericoid mycorrhizae.

[~156 MYA] ECTOMYCORRHIZAS FUNGI. ***EMF wraps a Hartig net outside the root tips***. "Ectomycorrhizas are intermediate in their ability to take up nutrients, being more efficient than arbuscular mycorrhizas and less so than ericoid mycorrhizas, making them useful in an intermediate nutrient situation." Ectomycorrhizas fungi are a necessity for most cold climate, flammable conifers. EMF also connects them to some moist and far less flammable deciduous trees for nitrates, special defensive capabilities, and sometimes seasonal carbohydrates.[7]

[~140 MYA] ERICOID MYCORRHIZAL FUNGI. ***Ericoid enters plants' root cells and is coil-like***. Ericoid fungi extended flora range to effectively handle nutrient-poor soils, dry soils, and especially acidic soils. This would allow future members of the Heath family (such as rhodora (pictured), blueberries, huckleberries, cranberries, Labrador tea, mountain laurel, azalea, and rhododendron) to live in such places.

In the Late Cretaceous, evolving bacteria, expanding sources of nitrates, and ever-improving mycorrhizal fungi collaboration allowed angiosperms (flowering plants), which had started around 150 mya or earlier, to begin to flourish. Soil stored more carbon, atmospheric CO_2 lowered, and atmospheric O_2 increased.[8]

[84-66 MYA] ORCHIDACEAE FUNGI. ***OF is also coil-like inside root cells***. In moist soils, OF serves orchids, including lady slippers and ladies' tresses. Dr. Santiago Ramırez: "Our results indicate that the most recent common ancestor of extant orchids lived in the Late Cretaceous and also suggest that the dramatic radiation of orchids began shortly after the mass extinctions at the K/T boundary. These results further support the hypothesis of an ancient origin for *Orchidaceae*." [9]

[35-24 MYA] C4 PHOTOSYNTHESIS. Responding to dryer microclimates, C4 started in grasses. 46% of grasses now have C4 photosynthesis. The C4 characteristic allowed plants to photosynthesize with less water. C4 photosynthesis has since developed for other plants even as recently as 5 MYA. This author's favorite C4 plant is purslane, with flowers that surprise him in sidewalk cracks. [10] >>> ***Arbuscular, Ecto, Ericoid, Orchidaceae mycorrhizae's and xylem's and C4's evolutions each advanced Earth's flora habitats, and, with them, soil's carbon storage.***

>>> Due to mycorrhizae's ongoing carbon soil storage, saprophyte fungi's processing of cellulose and lignin, and all of soil's natural collaborators, Earth's soil "contains twice the amount of carbon in all plants and Earth's atmosphere combined." Tragically, studies show current deforestation and its soil warming breaks carbon-soil bonds and causes high carbon losses from that soil for over 15 yrs and continuing losses for 30-40 yrs. *** Studies in Oregon, Idaho, British Columbia and elsewhere have concluded logging & wood products industry generates more carbon emissions than any other sector, including transportation.[11]

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[6] Xylem>lignin: *PBS Eons;* NS Davies U. Cambridge; P. Gerrienne U. Liege; D Wang U. Peking; Fungi: Wiki Paleomycology; M. Nelsen Stanford U; L Grand N. C. State U;

[7] Wiki. Ectomycorrhiza; H. Briggs 2018 "How Flowering Plants Conquered the World." *BBC News:* Besides many flammable conifers. EMF plants include; more fire-resistant oak and beech (with immunostimulant quercitrin), birch (with methyl salicylate), and hazelnut, linden/basswood, and hornbeam/ironwood. Having both AMF & EMF: pioneer plants: alder (nitrogen-fixer); aspen, poplar, and willow (all 3 have: plant immunostimulant: salicin ASA).

[8] Wikipedia Ericoid. 2019 "Flowering plants, new teeth and no dinosaurs: New study sheds light on the rise of mammals." *Phys.Org*. From Chen, Strömberg, & Wilson

[9] S. R. Ramırez *Nature* 448 (7157) 1042-1045; Kenji Suetsugu Kobe U.;

[10] Wikipedia C4 carbon fixation; U. Toronto study.

[11] Carbon soil storage: Swedish U. study; Princeton U. study; Dartmouth College Study; Soils emissions after deforestation: E. Humphreys UBC; A. Black UBC; C. Gabriel SFX; Forestry's role in Atmospheric CO_2: Oregon St. & Idaho U; BC study; Brazil study; Australian study; NC study; See Earth's CO_2 consequences & here.