Mycorrhizae Evolution - Expanding Flora's Range and Soil's Carbon Storage

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Liverworts, 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, farmer markets, thermometers, pharmacies, and vehicles to get them there, plants have stomata, roots of various thicknesses, lengths, and capabilities, and use of 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 were able to exchange sugar for hard to reach water, nitrogen, and nutrients, even in ancient, acidic, poorer, & drier soils.

Fungi can be generalists. Others have specific duties. Some share carbohydrates or amino acids, and others do not. Certain fungi forage for specific nutrients, in different places, or only for certain plants. ***After the exchange, fungi would secure their residue carbon under soil***. [2]

Each of Earth's million fungi types coevolved with flora within distinctive niches.

[500 MYA (million years ago.**)] ARBUSCULAR FUNGI.** ***AMF penetrate roots' cortical cells.***
To Earth's then, almost all barren rock surface, W. Rimington and P. Donoghue report AMF began coevolution with early liverworts or similar plants, and together they formed some of the first recycled soils.[3]


Granite moss / Earltown Mountain NS



Saprophyte fungi: Left: pink coral fungus. Right: with lichen and moss. All recycling fallen debris and trees

[466 MYA] MOSSES appeared on Earth's surface, processing nutrients out of Earth's rock mantle. Mosses 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 an ice age.

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. AMF continued its interaction and evolution when the first vascular plants emerged on the surface of the earth. This collaboration formed soil and lowered levels of atmospheric CO_2. This would cause a more significant ice age.

Early bryophytes and vascular plants would be followed by club moss, fern and horsetail.

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

[2] Dr. Suzanne Simard (UBC) 2021 Finding the Mother Tree. pp.60,68,80,98,167-170,222-223. Bob Yirka 2013 "Study finds fungi, not plant matter, responsible for most carbon sequestration in northern forests." Phys.org News. & Research of Karina Engelbrecht Clemmensen Swedish Univ. of Agri Sci. *Science*.

[3] William R. Rimington (Imperial College London) et al. (+ 5 others) 10 Oct. 2018 "Ancient plants with ancient fungi: liverworts associate with early-diverging arbuscular mycorrhizal fungi." *Proceedings of the Royal Society B Biological Sciences* See also Elizabeth Pennisi 19 Feb. 2018 *Science*.

[4] Sid Perkins 2012 "Did Plants Freeze the Planet?" *Science* & Tim Radford 2016 "All hail the humble moss, bringer of oxygen and life to Earth." *The Guardian*. From interviews and research of Dr. Tim Lenton (U. Exeter). Dr. Ruth Kimmerer. (State U. of NY) Gathering Moss 2003 p15. Tessa Koumoundouros 9 May 2023 *Science Alert*. From Dr. David Eldridge (U. of New South Wales) & 50 others 2023 *Nature GeoScience*. Also Oak Ridge National Laboratory sphagnum study.

[385 MYA] SAPROPHYTE FUNGI. A significant change to Earth's flora was the advent of the earliest tree, *Wattieza*, and, with it, ***saprophyte fungi, which broke down that tree's cellulose and lignin and exchanged the recovered carbohydrates and nutrients with their ecosystems***.[5] Potential CO_2 emissions were covered by moss, lichen, or topsoil.


White & gray birch serviced by Ectomycorrhizas


Blueberries serviced by Ericoid mycorrhizae fungi


Showy lady slipper serviced by Orchidaceae fungi

[Around 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, often cold climate, conifers. EMF also connects them to certain deciduous trees and plants for nitrates, special defensive capabilities, and sometimes seasonal carbohydrates.[6]

[Around 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 blueberries, huckleberries, cranberries, Labrador tea, rhodora, mountain laurel, azalea, and rhododendron) to live in such places. ***Mycorrhizae evolution has increased plant habitats & soil's carbon storage.***

In the Late Cretaceous, evolving bacteria, expanding sources of nitrates, and ever improving mycorrhizal fungi collaboration allowed flowering plants (angiosperms), which had started around 150 mya or earlier, to begin to flourish. Atmospheric CO_2 would consequently lower, and atmospheric O_2 increase.[7]

[84-66 MYA] ORCHIDACEAE FUNGI. ***OF is also coil-like inside root cells***. In moist soils, OF serves orchids, lady slippers and ladies' tresses. 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*." [8]

[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.

Due to mycorrhizae's ongoing carbon soil storage, its processing of decaying biota, and its natural collaborators, Earth's soil "contains twice the amount of carbon in all plants and Earth's atmosphere combined." Tragically, studies show current deforestation is causing high carbon losses from that soil for over 15 yrs and continuing losses for 30-40 yrs. [9]

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[5] Wikipedia Wattieza & Wikipedia Paleomycology

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

[7] 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

[8] Dr. Santiago R. Ramırez (UC Davis) et al. "Dating the origin of the Orchidaceae from a fossil orchid with its pollinator." Sept. 2007 *Nature* 448 (7157) 1042-1045

[9] Wikipedia C4 carbon fixation; U. Toronto study; Swedish U. study; Princeton U. study; A. Black UBC; C. Gabriel SFX; Oregon St. & Idaho U; NC study; BC study.