# Soil and Tree Health

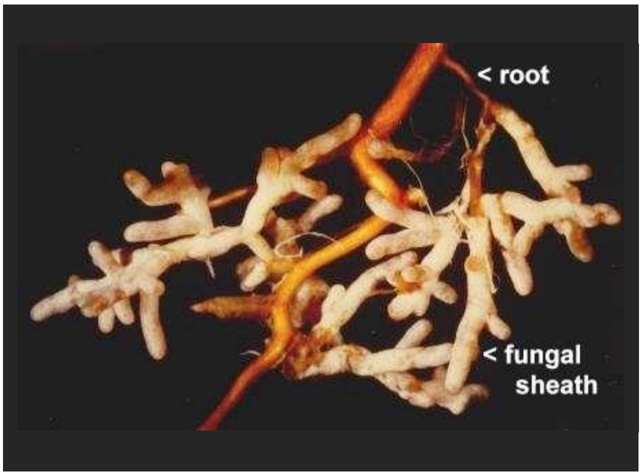
## Mycorrhizal fungi

Soils support a complex ecosystem and alongside water and air, are one the three major natural resources fundamental to supporting terrestrial life by allowing plants to thrive. This article looks specifically at one group of organisms, mycorrhizal fungi and the important collaborative relationship they hold with the majority of terrestrial plants.

Three basic components constitute soil (five if air and water are included). Soils comprise mineral particles, organic matter, and soil biota. The latter includes protozoa, bacteria, fungi, nematodes earthworms and arthropods; a healthy soil is teeming with such life. A single cup of soil contains more organisms, including kilometres of fungal hyphae, than humans that have ever lived on Earth (estimated at a little over 107 billion).

The word Mycorrhiza is derived from the classical Greek for fungus (myco) and root (rrhiza). A.B. Frank coined it in 1885 during research commissioned by the Prussian Agriculture minister to investigate ways to increase truffle production (sadly, he was unsuccessful in his task). Frank used the term to describe non-pathogenic symbiotic associations between roots and fungi. Mycorrhiza had been described as early as the 1840 by Hartig, who erroneously described them as “persistent periderm” and “peculiar wall structure” of root cells, failing to recognize their fungal origin. Although not the first to observe mycorrhiza, Frank was the first to correctly interpret the relationship between mycorrhizal fungus and plant roots, his theory inciting a botanical controversy lasting decades. The interaction between mycorrhizal fungus and roots has since been extensively studied elucidating many facets of the interaction, as well as raising many as yet unanswered questions.

Mycorrhiza are ancient organisms, appearing in the fossil record as early as the mid-Ordovician period (460 million years ago) where they have been associated with early land plants, liverworts and hornworts.




Mycorrhizas of the Fly Agaric toadstool (*Amanita muscaria*) [© Jim Deacon]
Source: Courtesy of Jim Deacon, The University of Edinburgh

Mycorrhizal short roots of pine seedlings forming connections with one another through mycelial cords which, presumably, facilitate transport of sugars and mineral nutrients (this being a common role of mycelial cord systems in general).
[© Jim Deacon]
Source: Courtesy of Jim Deacon, The University of Edinburgh

Their appearance predates the first vascular plant genera, Cooksonia and Rhynia, which appeared some 43 million years later. It has even been hypothesised that mycorrhizal fungi influenced the evolution of roots from rhizomes to provide more suitable habitats for mycorrhizal fungi, whilst facilitating the evolution of plant complexity. It is therefore conceivable that mycorrhizal associations assisted plants in successful colonization of terrestrial environments.

This association early in plant evolution may explain why mycorrhiza are so ubiquitous throughout the plant kingdom. Associations are often non-selective, and in some instances obligate, with over 80% of angiosperms and 100% of gymnosperms examined forming mycorrhizal associations. And whilst there are neutral and even parasitic relationships between plants and mycorrhizal fungi, most relationships are mutually beneficial.


Mycelium of mycorrhizal fungi causes soil aggregation and stabilisation
Source: PlantaGlobe.com

There are seven known types of mycorrhiza, including ectomycorrhiza, endomycorrhiza (formerly known as arbuscular mycorrhiza), orchid mycorrhiza, ericoid mycorrhizza, arbutoid mycorrhizza, monotropidmycorrhizza and ectendomycorrhizza.

Globally however, the two most widespread are endomcyorrhiza, and ectomycorrhiza. Ectomycorrhizza do not penetrate root cell walls, forming instead a dense sheath around the developing root tip and a network of hyphae that extend into the root, penetrating the intercellular spaces, between the epidermal and cortical cells (Hartig net). Endomycorrhizal fungus hyphae do penetrate root cell wall forming distinct structures; either balloon like arbuscles or branching fan like vesicles.

Endomcyorrhiza are the most abundant type found in over 70% of all plants, common in most habitats and dominant in deserts, temperate grasslands and tropical environments. Yet just over 200 species of these fungi are described. By contrast there are over 6,000 known species of ectomycorrhizzal fungi, though they are associated with significantly less plant species, mainly woody shrubs and trees, being dominant particularly in alpine and cold arboreal coniferous forests, temperate forests, Mediterranean areas and to a lesser extent savannah, sub-tropical and tropical environs.

There are also over seventy plant families in which most or all genera do not form mycorrhizal associations (non-mycorrhizal). Non mycorrhizal plants are most common in disturbed habitats, sites with extreme environmental or depaurperate soil conditions and include many colonizers (Cyperaceae, Juncaeae), weed species (Chenopodiaceae, Cruciferaceae, Portulacaceae), parasitic and semi-parasitic plants (Balanophoraceae Santalaceae), carnivorous plants (Droseraceae, Lentibulariaceae), plants with cluster roots (Proteaceae), and aquatic plants (Cymodoceaceae). Not surprisingly given the large areas of highly infertile soils, non-mycorrhizal plants appear to be more common in Australia than in other continents.

The main benefit of the mycorrhizal association are the transfer of carbon from plants to fungus (in some instances up to 40% of the plant produced carbohydrates), and mineral nutrients from the fungus to the host plant through three main ways: increasing nutrient uptake by extending the volume of soil accessible to plants, by mobilising nutrients that would otherwise be unavailable to plants and by excreting chelating compounds or ectoenzymes. Other described benefits include:

- Improved resistance to soil borne pathogenic microorganisms.
- Improved water relations improving plant tolerance toward drought.
- Extending the life of fine roots including physically protecting the root tip.
- Moderating excessive nutrient levels / enable plants to tolerate toxic elements.
- Improving soil structure through exudation of glomulin.

Furthermore, the non-specific nature of many mycorrhizal associations appears to have broader implication for ecosystem sustainability via their ability to form common mycorrhizal networks (CMN). Recorded as early as the 1960's, CMNs occur where one or more mycorrhizal fungus colonizes multiple plants of one or more species. CMNs can provide pathways for carbon and nutrient exchange between plants of different species thereby reducing competition for nutrients between plants. The supply of nutrients to non-photosynthesising plants has been found, and it has been also suggested that CMN may help seedlings become established and contribute to the growth of shaded understorey plants through nutrient and water redistribution. CMN may even play a role in nutrient cycling providing nutrient transfer from dead to living plants.

With the potential benefits of increasing plant nutrient content, and yield, as well as 'fortifying' plants against adverse conditions and pathogens, there has been much interest and research into the application of mycorrhizal fungus inoculums for application in the forestry, horticulture and agriculture industries as well as plant establishment for ecosystem restoration. Yet despite this, potential mycorrhizal products are still largely experimental and inoculation of crops at least in agriculture and horticulture is not yet widespread. Forestry however, has commonly used mycorrhizal inoculation in forestry plantings to promote growth and tree health for several decades. As an industry, it could be considered a pioneer in research, contributing significantly to our current knowledge and understanding of the topic.

A more recent development in the commercial use of mycorrhizas has been for land reclamation and bioremediation of contaminated sites, capitalizing on mycorrhizal plants increased tolerance of heavy metals in soils over non-mycorrhizal plants and the ability of mycorrhiza to improve soil structure, contribute to nutrient cycling, as well as creating habitat for other soil biota.

The efficacy of inoculums is influenced not only by plant species suitability to the fungal species contained in the inoculum but also by the climatic conditions, the physical, chemical, and biological properties of the soil where the inoculum is used relative to the inoculum origin, as well as the interaction of introduced mycorrhizal fungus with existing native mycorrhizal fungus and other soil biota populations.

One of the difficulties with understanding the benefits of off-the-shelf commercial products is the variation between products. Differences include carrier medium and non-mycorrhizal additives, the mycorrhizal types and species mix present, the number of active spores per unit weight or volume, the prescribed dosage, the soil properties of where the fungus were collected in relation to soil properties of where it will be applied. The lack of information and apparent lack of expertise in product manufacture makes it difficult to know with confidence what product may be suitable for any particular application. Often the claims cannot be replicated through independent testing; benefits are limited or are associated with other additives in the inoculum. Not surprisingly, this is in stark contrast to much of the product labelling and marketing.

Research has demonstrated benefit to major crop plants including maize, wheat and barley, with success also documented with onions, and more recently rice, millet and yam tubers. Whilst there is still much to learn about mycorrhizal associations to properly evaluate their potential for broad commercial use particularly in horticulture and agriculture, a better understanding of mycorrhiza and manufacturing expertise may lead to a future less reliant on fertilizers, pesticides and fungicides.

---

**References**

Australian National Botanic Gardens (n.d.), *Mycorrhizas*, http://www.anbg.gov.au/fungi/mycorrhiza

Brundrett, M. C. (2002). "Coevolution of roots and mycorrhizas of land plants". *New Phytologist* 154 (2): 275

Brundrett, M. (2008) *Mycorrhizal Associations; the web resource*, http://mycorrhizas.info/roles.html

Cairney, J., W., G. (2000) Evolution of mycorrhiza systems; *Naturwissenschaften* (2000) 87:467–475, http://www.springer.com

Bonfante, P., Genre, A., Plants and arbuscular mycorrhizal fungi: an evolutionary-developmental perspective, *Trends in Plant Science,* Vol.13 No.9, pp 492-498, http//:www.elsevier.com

Bowen G., D. (1965) Mycorrhiza inoculation in Forestry Practice, *Australian Forestry*, vol. 29: 4, 1965, pp 231-237.

Channabasava, A., Lakshman, H., C (2010)Use of Mycorrhizal Inoculum as a Soil Amendment During Prairie Restoration, *Karnataka J. Agric. Sci*., vol.24 (3) : (309 - 311) 2011

Corkidi, L., Allen, E., B., Merhaut, D., Allen, M., F, Downer, J., Bohn, J Evans, M Assessing the Infectivity of Commercial Mycorrhizal Inoculants in Plant Nursery Conditions, *J. Environ. Hort*. 22(3):149–154. September 2004

Cripps, C. L., 'Mycorrhiza', in *Pacific Northwest Plant Disease Handbook*, Oregon State University, http://pnwhandbooks.org/plantdisease/pathogen-articles/

Faye, Y., Dalpe, K., Ndung'u-Magiroi, J., Jefwa, I., Ndoye, M., Diouf, D., L, (2013) Evaluation of commercial arbuscular mycorrhizal inoculants, *Canadian Journal of Plant Science*, http://pubs.aic.ca/doi/abs/10.4141/cjps2013-326.

Fernández, F., Del'Amico, J., M., Angoa, M., V., de la Providencia, I., E., (2011) Use of a liquid inoculum of the arbuscular mycorrhizal fungi Glomus hoi in rice plants cultivated in a saline Gleysol: A new alternative to inoculate, *Journal of Plant Breeding and Crop Science* Vol. 3(2). pp. 24-33, February 2011

Haub C, (2011) *How Many People Have Ever Lived on Earth?* http://www.prb.org.aspx

Ianson, D., Smeenk, J., (2010) Mycorrhizae in the Alaska landscape, HGA-00026, University of Alaska Fairbanks 2010, http://www.uaf.edu/

Jacobsen, I., Rosendahl, L., (1989) Carbon flow into soil and external hyphae from roots of mycorrhizal cucumber plants, *New Phytol*. (1990), 115, 77-83

Klecsweski, N., Wang, D., Herms, D., Bonello, P., (n.d.) *The effects of soil type, fertilization, and Mycorrhizal inoculation on paper Birch (Betula papyrifera) in a simulated urban setting*, The Ohio State University, Columbus Ohio.

Malloch, D., W., Pironzynski, K., A., Raven, R., H., (1979) Ecological and evolutionary significance of mycorrhizal symbioses in vascular plants (A Review), Proc. Nati. *Acad. Sci*. USA Vol. 77, No. 4, pp. 2113-2118.

Population Reference Bureau http://www.prb.org/ 107,602,707,791 as at mid 2011, http://www.prb.org/Publications/Articles/2002/HowManyPeopleHaveEverLivedonEarth.aspx

Rotor, V., A., Delima, P., C (2010) Mycorrhizal association, n fertilization and Biocide application on the efficacy of Bio-n on corn (zea mays l.) Growth And productivity, E-International Scientific Research Journal, vol. 2 Issue: 3, 2010, pp267-290.

Selosse, M-A., Richard, F., He, X., Simard, S., W, (2006) Mycorrhizal networks: des liaisons dangereuses?, *Trends in Ecology and Evolution* Vol.21 No.11, pp621-628, http//:www.sciencedirect.com

Simberloff, D., Rejmánek, M., (ed) (20111) editors, *Encyclopaedia of Biological Invasions*, Berkeley and Los Angeles: University of California Press, pp. 468-471.

Swift, C (n.d.) Mycorrhiza and its uses: Fact or Fiction, PowerPoint presentation, Colorado State University, Colorado

Tallasken, J., (1997) Use of Mycorrhizal Inoculum as a Soil Amendment During Prairie Restoration, *Restoration and Reclamation Review*, vol. 2, no.5, Spring 1997, University of Minnesota.

Tarbell, T., J, Koske, R., E (2007) Evaluation of commercial arbuscular mycorrhizal inocula in a sand/peat medium, Mycorrhiza, (2007)18, pp. 51-56, http://www.springer.com

Tchabia, A., Coyned, D., Hountondjib, F., Lawouinb, L., Wiemkena, A., Oehla, F., (2010) Efficacy of indigenous arbuscular mycorrhizal fungi for promoting white yam (Dioscorea rotundata) growth in West Africa; *Applied Soil Ecology*, Vol. 45 (2010) pp. 92–100., http://www.elsevier.com

Toro, M., Azco'n, R., Barea, J-M., (1997) Improvement of arbuscular mycorrhiza development by inoculation of soil with phosphate-solubilizing rhizobacteria to improve rock phosphate bioavailability (32P) *Applied and Environmental American Microbiology*, vol. 63, No. 11 Nov. 1997, p. 4408–4412

Trappe ,J., M., (2004), A.B. Frank and mycorrhizae: the challenge and ecologic theory; *Mycorrhiza*, (2005), vol. 15, pp. 227-281.

Vellinga, E., E. (2008) A Mycolegium of Literature; *Fungi,* vol. 1: 3 (2008), pp. 31-33, http://www. nature.berkeley.edu

Warren JM, Brooks JR, Meinzer FC, Eberhart JL. (2008) Hydraulic redistribution of water from Pinus ponderosa trees to seedlings: evidence for an ectomycorrhizal pathway. *New Phytol*. 2008; 178(2): pp. 382-94, http://www.ncbi.nlm.nih.gov/

Images from: www.PlantaGlobe.com and Courtesy of Jim Deacon, The University of Edinburgh