# MYCORRHIZA – a brief introduction

**"While there are many groups of soil organisms that may be considered to provide 'keystone' ecosystems functions, mycorrhizal fungi are arguably among the most important because of their direct access to the plant-derived carbon that fuels below-ground microbial communities."** Leake, J.R. *et al.* (2005). In Badgett, R.D., Usher, M.B. & Hopkins, D.W. eds *Biological Diversity and Function in Soils*. Cambridge University Press.

**"Mycorrhizas, not roots, are the chief organs of nutrient uptake by land plants."** Smith, S.E. & Read, D.J. (2008). *Mycorrhizal symbiosis*. 3rd ed. Academic Press.

**MYCORRHIZA** is a symbiosis, that is: two or more different organisms living together. It is arguably one of the most important life processes on land, but being subterranean, microscopic, invisible and poorly understood, it is not an easy concept to comprehend or to share with others. To invisibility we can add the perplexingly complicated and obscure ecology of mycorrhiza, which is just too much hassle for many of the scientists in whose studies it ought to be relevant, even ecologists. Some simply can't cope with including it in their comfortably simplified description of the world, and they just leave it out. That is a shame, because it matters a great deal (gross understatement – above). This handout tries to make mycorrhiza accessible to all, providing some clarity in advance of the talk.

This tongue twister combines two Greek words μυκας–ριζα (*mikas-riza*), literally 'fungus-root'. In a mycorrhiza, specialised fungi invade plant roots where they form an interface for the exchange of nutrients. From the 'phytocentric' (plant's) viewpoint, its most usual function is to facilitate the supply of phosphate. This essential nutrient generally occurs at extremely low concentrations in natural soils and is mostly held tightly by soil clays, unavailable. Don't worry, *'twas ever thus*, and mycorrhiza is the remedy. No, remedy is the wrong word. It's the norm. For instance, the roots of Britain's favourite wild flower, bluebell (*Hyacinthoides non-scripta*), operate in an environment where phosphate is available at less than 0.1 part per million in soil solution. Bluebells cannot survive if non-mycorrhizal, for their short, thick roots are incapable of exploring the soil for inaccessible nutrients. Long ago evolution and symbiosis took care of what would have otherwise have been a fatal problem for bluebells. At Pretty Wood in Yorkshire, bluebell roots are colonised by at least eleven different mycorrhizal fungi, most of which are unculturable, unidentifiable and new or unknown to science. They range out beyond the root system, some of them gathering otherwise inaccessible phosphate on the behalf of their plant partners, others working with bluebell in different ways. It works very well.

This is not a new idea, even in evolutionary terms. In the primeval, aquatic habitat, primitive plants found phosphate acquisition uncomplicated, but it was not so when they experimented with life on land. When they first embarked upon their land-based lifestyle together around 500 million years ago, plants and mycorrhizal fungi were already collaborating in the form of a novel symbiosis which enabled them both to live on land and diversify. From the start, mycorrhiza was the normal way of life for land plants, and it still is for an estimated 90-95% of plants in all ecosystems on every continent. Mycorrhiza was, always has been and still is ubiquitous. *Please read the last two sentences again to absorb what they imply about the universal ecological importance of this symbiosis!*

We tend to focus our attention on the above-ground organisms with which we are familiar, the ones that occupy the same living space as ourselves. Therefore, we overlook the 'mycocentrically' (fungal viewpoint) important function of mycorrhiza: what do the fungi get out of it?

Mycorrhiza comes in at least five distinct forms that all evolved separately and are really completely different. Sorry, this can't be made any simpler:

1. The first and original, the one that enabled life on land, is arbuscular endomycorrhiza (AM) involving a wide range of plants (about 75% of the total) and little known fungi of the Glomeromycota.

2. Many trees (by no means all, for many are AM), shrubs and a few herbs form ectomycorrhizas (EcM) with fungi of the basidiomycota, many of which produce the mushrooms we find on the forest floor (and eat).

3. The heathers and related plants form ericoid mycorrhizas (EM) with their own special fungi …

4. … as do orchids (OM).

5. Then there is the extraordinary three-way symbiosis known as mycoheterotrophy (used to be misunderstood, named saprotrophy) in which a pale plant that lacks chlorophyll taps into a tree's ectomycorrhizal to obtain its carbon supply form the tree, via the fungus.

6. Even more amazing is mixotrophy, which is like mycoherotrophy but the plant is green and can make its own carbohydrate.

7. And more amazing yet – it might seem not, though I think so – is the non-mycorrhizal condition, which has evolved relatively recently. Plants have discovered alternative means of obtaining, e.g. phosphorus.

Important, but frequently overlooked, are the minority of plant species that are mycorrhiza-independent or non-mycorrhizal. Some, such as the Proteas of South Africa and Australasia and pioneers of new ground are very specialised plants whilst others now play their own significant roles in our world as food plants and weeds. They are often the main inhabitants of disturbed and degraded soils whereas mycorrhizal plants tend to live under more stable circumstances in the highly developed natural ecosystems we are today struggling to protect as they are damaged, simplified and replaced with crops and wasteland.

From the outset, man's intervention set in motion a series of disasters for naturally sustaining, symbiotic communities. Yes, worms, rabbits, tree wind-throw and earthquakes all disturb the soil, but only in isolated patches that all the constituent species can rapidly recolonise. This sort of disturbance is built into soil ecological processes for it releases localised bursts of nutrients promoting soil heterogeneity and ecosystem biodiversity. Agricultural tillage often affects vast areas, repeatedly exterminating soil organisms by exposure and, in the case of the fungi which form wide-ranging networks, also fragmentation. Destroy mycorrhizal fungi, and plants that are dependent upon them die, whilst populations and communities of adaptable plant species will be compromised. The fungi themselves are not so adaptable. They are entirely dependent upon their plant partners, for they are unable to produce a basic foodstuff, carbohydrate, themselves but they do obtain it through the symbiosis. If separated from their plants, they cannot adapt; cannot survive. Therefore, if you remove the fungi, plant populations disintegrate and if you remove the plants you kill the fungi. Whether you take the viewpoint of the plants or the fungi, it is symbiosis that keeps them alive and symbiosis that is disrupted by man who must share the consequences. Essentially, it is the symbiosis that maintains biodiversity which plummets in the wake of anthropogenic disturbance.

As a quick aside, and to illustrate a parallel of mycorrhiza, corals are symbiotic with carbohydrate manufacturing 'dinoflagellates'. A rise in sea temperature of around 2 °C is sufficient to separate this vital partnership. As the oceans warm, coral reefs, which support marine communities important to both planet and man, become bleached and die. Full stop.

Mycorrhizal partnerships can be highly specific. Not only is there specificity between certain plants and certain fungal species (some of either can be also be generalist and promiscuous) but, with variability in time and space, the way partnerships function can also be very specialised. Therefore, if components of a community are removed, community structure is soon compromised. Remove a lot of them and ecosystem structure and integrity will collapse. Large-scale ecosystem collapse has been predicted, and has actually occurred if only we could see it. Mycorrhiza is a mechanism which might help explain what is happening.

Ecosystem collapse must be occurring with the progress of deforestation and intensive agriculture, and not just because wild plants are exterminated. Remove a diverse forest community and collateral extinctions below ground mean that thereafter the soil can support no more than a few adaptable weed species; until the soil community has been rebuilt, which requires the presence of reserves of all the original organisms beyond the margins of the devastated area. If the area to be recolonised is large and potential recolonisers locally extinct, restoration is likely to take a long time or fail. Hence, it will take centuries for a landscape to reassemble itself. Eventually, after a very long period of recovery, it might begin to resemble something we humans would accept as natural, but it probably won't be, particularly if some extinctions were widespread rather than local.

*We* can't reassemble complex ecosystems properly ourselves because we don't know what they were originally. Planting countless millions of trees of the sorts we are able to grow does not make real forests. It's what I call Naïve Conservation.

Ice sheets sweep away everything living, but when they retreat, soils and ecosystems rebuild rapidly. Thus, after the last ice ages, it took northern lands less than 10,000 years to recover reasonable biodiversity, which is feeble compared with that of tropical rain forests, the sort that support an amazing up to 200 tree species per hectare. Their fabulous biodiversity took a lot longer to develop, though ice probably once affected their continents as they drifted about the globe millions, rather than thousands, of years ago. Today, we can see how rapidly soils and communities form when quarries, exposures of bare rock, a clean canvas, are abandoned and left to nature.

Thanks to contamination, not just by pesticide residues, agricultural land in the 'developed' world, is probably a worse starting point for ecosystem restoration than bare rock. At low concentrations, soil phosphate is a vital nutrient in biological communities that can recycle it efficiently. In agricultural circumstances, where populations of mycorrhizal fungi are impoverished, we find we have to keep adding phosphate to soils so that crops will grow. Therefore, when it is added in large quantities as an artificial fertiliser and not utilised or recycled, phosphate becomes a pollutant. Only phosphate in soil solution is available to roots unaided, and even then it does not flow in soil in they way that does, say, dissolved nitrate. Excess becomes attached to soil particles, out of reach to many root systems: 'stuck' so that only specialist fungi can gather it. Phosphate-rich soils (fertilised, enriched, disturbed, abused soils) actively inhibit the formation of mycorrhizas and favour non-mycorrhizal plants and, therefore, ecosystems become permanently changed, usually not for the better.

When we add phosphate to crops, even the few, tough, generalist mycorrhizal fungi that have survived mechanical assault are physiologically excluded from roots by their plant hosts, cutting off the last remains of the phosphate acquisition service they would receive free of charge in an intact natural community. Thereafter, plants must gather their own phosphate. The majority cannot, but some can: weeds.

James Merryweather (based on 'Secrets of the Soil'. *Resurgence*, March/April 2006)

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## FOOD FOR THOUGHT

"The agriculture of ancient Rome failed because it was unable to maintain the soil in fertile condition. The farmers of the West are repeating the mistakes made by Imperial Rome". Sir Albert Howard, 1940

"Few things matter more to human communities than their relations with the soil. The biology of soil is of fundamental importance to the sustainability of life on earth … soil remains the least understood, and perhaps the most abused, habitat on Earth". Prof. Richard Bardgett, 2005

"The soil is the major natural resource available to mankind, yet it has been abused by us to the point of self-destruction. Many past civilizations have perished due to their abuse of the soil (e.g. Rome, Mesopotamia and the Mayan civilization)". Anon.

"It is helpful and not so far-fetched to think of the soil as itself an organism - a social organism like a human society, for example the manifold vital activities of which are carried on by its numerous living inhabitants.

Disturbance of anyone of these activities may affect others and thus lead to loss of equilibrium and the appearance of symptoms of disorder, with eventually an increasing degree of biological inertia of one kind or another, a condition just the reverse of the vital activity characteristic of a living and fertile soil".

M.C. Rayner, 1945

"Soil is not only the skin of the earth and a rich but mostly unexplored world, but also the very foundation of human existence." Prof. Edward O. Wilson, 2006

"Living soils are a natural resource we cannot afford to deplete." Prof. Diana Wall, 2006

"Virtually all terrestrial ecosystems are founded on soil. Plants rely on it for water and nutrients, as consequently does everything else in the ecosystem, including us. Yet our species' blithe disregard for soil is evidence of our reluctance to understand its fundamental role in our welfare. Many of the great ecological disasters in history occurred when inappropriate farming techniques were applied to fragile soils, a well known example being the dust-bowl of the American mid-west that inspired John Steinbeck's classic novel *The Grapes of Wrath* … Our appetite for destroying soils continues." Prof. Alastair Fitter CBE, FRS, 2005