

Mycorrhizal fungi - powerhouse of the soil

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The soil foodweb of microflora and microfauna constitutes an underground engine of fundamental significance to plant productivity. Mycorrhizal fungi play a key role in the functioning of this foodweb, drawing down atmospheric CO₂ as dissolved organic carbon (DOC) and providing much-needed energy for the soil ecosystem. Mycorrhizal fungi also improve aggregate stability, enhance soil structure, build stable soil carbon, improve plant water use efficiency and increase the efficiency of utilisation of important nutrients like phosphorus, sulphur and nitrogen.

Agricultural research tends to focus on conventionally managed crop and pasture lands where loss of diverse perennial groundcover and/or intensive use of agrochemicals, have dramatically reduced the number and diversity of soil flora and fauna, including beneficial microbes such as mycorrhizal fungi. As a result, the potential contribution of microbial symbionts to agricultural productivity has been greatly underestimated.

What are mycorrhizae and how do they work?

Vesicular arbuscular mycorrhizae (VAM) are 'obligate fungal symbionts', meaning they must form an association with living plants. They acquire their energy in a liquid form, as dissolved organic carbon, siphoned directly from actively growing roots. Mycorrhizal fungi cannot obtain energy in any other way. They have mechanisms enabling them to survive while host plants are dormant but cannot survive if host plants are removed.

Mycorrhizal fungi produce thin, hair-like threads of cytoplasm (hyphae) with a hyphal tip at each end. One tip enters a plant root and the other tip explores the soil matrix. Although the hyphae are small in diameter (usually less than 10 µm), the mycelial network can extend across many hectares.

Mycorrhizal fungi have a fan-shaped architecture (Fig.1), with long runner hyphae branching into networks of narrower and narrower absorbing hyphae. There can be over 100 hyphal tips at the end of each runner. These networks extend from the root system into the bulk soil, well beyond the zone occupied by the roots and root hairs. The absorptive area of mycorrhizal hyphae is approximately 10 times more efficient than that of root hairs and about 100 times more efficient than that of roots.

An amazing symbiotic relationship

Plants colonised by mycorrhizal fungi can grow 10-20% faster than non-colonised plants, even though they are 'giving away' up to 40-50% of their photosynthate to support mycorrhizal networks (photosynthate is the soluble carbon the plant fixed from CO₂ and sunlight). One of the reasons for this apparent paradox is that plants colonised by mycorrhizae exhibit higher

leaf chlorophyll contents and higher rates of photosynthesis than non-colonised plants. This enables them to fix greater quantities of carbon for transfer to fungal hyphae in the soil.

In exchange for soluble carbon from their host, mycorrhizal fungi supply nutrients such as phosphorus, zinc, calcium, boron, copper and organic nitrogen. It's an amazing symbiotic relationship. Mycorrhizal hyphae have a tubular vacuole system that allows bidirectional flow. That is, dissolved organic carbon from the host plant and nutrients from the soil, can move rapidly and simultaneously in opposite directions.

All groups of mycorrhizal fungi require a living host, but there's more to it than just plants and fungi. A wide range of associative microflora are also involved. For example, colonisation of plant roots by mycorrhizae is enhanced by the presence of certain 'helper' bacteria. There are also active colonies of bacteria on the hyphal tips, producing enzymes which solubilise otherwise unavailable plant nutrients.

Mycorrhizae and soil carbon

Glomalin, a long-lived glycoprotein (protein containing plant sugar) is a highly stable form of soil carbon that provides a protective coating for the hyphae of mycorrhizal fungi. Networks of fungal hyphae also provide an important first step for the polymerisation of dissolved organic carbon, ultimately leading to the formation of humus, a high molecular weight gel-like substance that holds four to twenty times its own weight in water. Humic substances significantly improve soil structure, porosity, cation exchange capacity and plant growth.

Both glomalin and humus are of significance to the current debate on soil carbon transience, as these stable soil carbon fractions cannot be lost from soil during droughts or fires.

Marie Spohn from the Universität Oldenburg has identified mycorrhizae (and the glomalin they produce) as the primary soil carbon stabilisation mechanism in sandy soils. Previously, soil scientists have considered carbon sequestration potential to be constrained by the soil's clay content. The new findings are good news for WA farmers, opening the way for much greater levels of carbon increase in agricultural soils than previously thought possible.

Land management impacts

Increasing the amount of stable carbon stored in agricultural soils via mycorrhizal fungi will require a redesign of many current land management techniques. Factors negatively impacting on mycorrhizae include lack of continuous groundcover, single species crops and pastures (monocultures)

Continued

and application of herbicides, pesticides or fungicides.

Mycorrhizal fungi are also inhibited by the application of large quantities of water-soluble phosphorus and by the presence of non-mycorrhizal crops (such as canola). Tillage has a less detrimental effect than previously assumed. Recent studies have shown that the use of chemicals is more harmful than moderate soil disturbance. Biology friendly farming practices based on living plant cover throughout the year (eg cover cropping or pasture cropping) and the use of biofertilisers, enhance mycorrhizal abundance and diversity and are more beneficial for soil health than chemical farming systems based on intermittently bare soils and minimal soil disturbance.

Due to their low abundance in annual-based or conventionally managed agricultural landscapes, the important role of mycorrhizal fungi in nutrient acquisition, plant-water dynamics and soil building processes has been largely overlooked.

The types of fungi that tend to survive in conventionally managed soils are non-mycorrhizal, that is, they use decaying organic matter such as crop stubbles, dead leaves or dead roots as their energy source rather than being directly connected to living plants. These non-mycorrhizal fungi have relatively small hyphal networks.

Mycorrhizae and water

It is well known that mycorrhizal fungi access and transport nutrients in exchange for the carbon from the host plant. What is less well known is that in seasonally dry, variable, or unpredictable environments (ie most of Australia), mycorrhizal fungi play an extremely important role in plant-water dynamics. The hyphal tips are hydrophilic (both the end in the plant and the end in the soil) enabling both water and nutrients to diffuse from one end to the other along a moisture gradient.

Mycorrhizal fungi can supply moisture to plants in dry environments by exploring micropores not accessible to plant roots. They can also improve hydraulic conductivity by bridging macropores in dry soils of low water-holding capacity (such as sands).

Further, mycorrhizal fungi can increase drought resistance by increasing the number and depth of plant roots.

Perennial grasses and mycorrhizae

Higher densities of mycorrhizal hyphae are found in healthy perennial grasslands than in any other plant community. It has been estimated that the hyphae in the top 10 cm of four square metres (4m²) of perennial grassland, if joined end to end, would stretch all the way around the equator of the earth.

Broadacre cropping could benefit enormously from widely spaced rows or clumps of long-lived perennial grasses and/or mycorrhizal fodder shrubs. As yet we do not know the required critical mass to improve soil ecosystem function, but it might only need to be 5-10% perennial cover. In diverse plant communities, mycorrhiza compatible plants join common mycelial networks called guilds. These networks connect plants with each other, enabling exchange of nutrients and water. This may help explain why mixed plant communities often perform better than monocultures.

In addition to the resilience conferred by mycorrhizal guilds, the benefit of permanent mycelial networks in terms of aggregate stability, porosity, improved soil water holding capacity, reduced erosivity and enhanced nutrient availability in soils are immense.

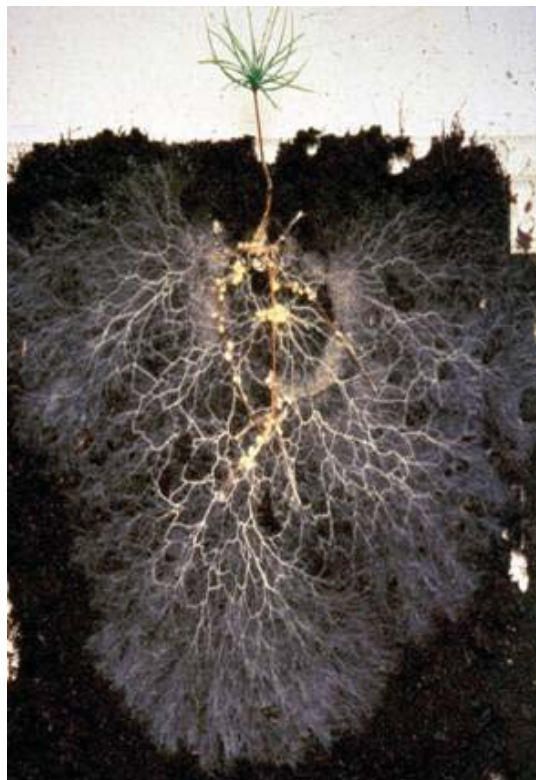


Fig.1. Mycorrhizal hyphae (white) colonising the roots (yellow) of a pine seedling. Photo courtesy Aberdeen Mycorrhiza Research Group

Soil benefits in many ways from the presence of living plants year-round, due to reduced erosion, buffered temperatures, enhanced infiltration and markedly improved habitat for soil biota. Significantly, it is the photosynthetic capacity of living plants (rather than the amount of dead biomass added to soil) that is the main driver for soil carbon accumulation.

Management techniques that improve the vigour of groundcover, foster mycorrhizal colonisation, increase glomalin production and enhance the humification process, will contribute to long-term carbon storage, improved soil function and markedly increased resilience to climatic variability.