Fungi living in a symbiotic relationship with plant roots help with nutrient uptake as well as enhancing disease resistance. James Wakeley explains how

Most plant species exploit their growing environment with the help of beneficial micro-organisms within the soil. One group of these micro-organisms, arbuscular mycorrhizal fungi, have co-evolved over 500 million years to form a symbiotic relationship with 90 per cent of all land plant families. This relationship was only identified in the last century, with detailed investigation taking place in the last 30 years. Products incorporating this technology have only been commercially available in the last ten years.

These fungi colonise plant roots, sending an extensive network of fungal filaments (hyphae) into the surrounding soil. These filaments are highly adapted to an efficient uptake and transfer of nutrients to plants, and are more efficient than the plants' own roots at extracting water and nutrients from the soil. This relationship can therefore make available to the plant sources of food and moisture which are normally inaccessible. In effect, the fungus provides a secondary root system — one that can be considerably more efficient and extensive.

There are several types of mycorrhizal fungi. The most common, arbuscular mycorrhizal fungi (AMF) colonise the roots of over 90 per cent of land plant families. The second most extensive group, ectomycorrhizal fungi (ECMF), are more host-specific, colonising the roots of many tree species — indeed some tree species associate almost uniquely with one or two fungal species. However usually a wider fungal species range is associated with one tree species. The relationship can also change during the life of the tree, with different fungal species being dominant at different stages during its life.

Some tree species form relationships with both of these fungal groups. Other kinds of mycorrhizal fungi are more often associated with specific plant families — for instance the heathers and orchids.

In many man-made landscapes soil micro-organisms, including mycorrhizal fungi, are necessary for the naturally efficient establishment and growth of plants. Such denuded or degraded environments force the plant to try and grow without its natural fungal partner, thus increasing plant stress and, often, its dependence on artificial nutrient inputs.

High levels of fertilisers (especially inorganic phosphate formulations), frequent fungicide applications, high levels of soil tillage (ie agriculture) or where plant growth is poor as the result of adverse soil conditions eg soil pollutants, all cause a dramatic reduction in natural soil inoculum — the levels of fungal propagules found in undisturbed ecosystems. An example of this can be seen in the Australian soil disorder known as 'long fallow disorder' caused by a lack of mycorrhizal fungi in soils, the result of extended periods of fallow or long cycles of non-host crops. These include oil seed rape, and brassicas which have evolved a very well developed, fine root architecture which has reduced their reliance on mycorrhizal fungi for plant nutrient uptake.

In nature, the majority of plants are mycorrhizal, certainly all trees. Plant communities are in fact stabilised by the diversity of mycorrhizal fungi below ground, which interlink plants (including trees) as part of our diverse ecosystems. In agriculture where soils are frequently disturbed season-on-season and pesticides and fertilisers added, only those mycorrhizal fungi capable of tolerating such abnormal conditions will survive and colonise roots.

While the influence of mycorrhizal fungi on plant growth and development, under these conditions, may be reduced, there is little evidence that they have direct negative effects on plants. In contrast their absence would restrict the growth of many dependent crops in agriculture, such as leeks and onions.

The push for high yields in agriculture and horticulture has led to plant cultivars being less susceptible to mycorrhization, so that the benefits accruing to plants from the symbiosis are reduced in some cases. However,
Dipping of silver birch whips in Terravit-G prior to planting out. The mycorrhizal fungi propagules contained within the product stick to the bare roots of the plant with the use of a gel formation where intermittent drought stress occurs (as seen more frequently in the south-east of UK in recent times), there is clear evidence that even plants growing in soils with high fertiliser additions suddenly acquire increased mycorrhization to cope with these sudden adverse environmental conditions.

The lack of a mycorrhiza relationship is now recognized to be a major cause of poor plant establishment and growth, and low survival rates, in a variety of agricultural, urban and industrial landscapes. The benefits of re-establishing mycorrhizal fungi in environments with low existing levels, have included:

- Increased plant nutrient uptake, in particular phosphate
- Increased tolerance of root pathogens
- Increased tolerance of water stress and adverse environmental conditions (e.g. heavy metal pollutants)
- Increased efficacy of Nitrogen (N)-fixation by rhizobium (plant nodulating bacteria which fix atmospheric N, making it available for uptake by plants)
- Increased plant biodiversity in restored ecosystems
- Increased stability of soils (erosion control)

**Plant nutrient uptake**

The nutrient most commonly associated with mycorrhizal benefit has been phosphorus (P), which is highly immobile in most soils. This lack of mobility can limit plant growth and reproduction. The effect of the symbiosis is to increase early growth by enabling the enhanced nutrient uptake of phosphate. This uptake and transfer of mineral elements is done by the fungal hyphae once established, as it provides an increase in exploited soil volume beyond that of the plant’s own root system.

**Increased resistance to root pathogens**

AMF have been shown to increase resistance to root-infecting pathogenic fungi such as Phytophthora parasitica or Fusarium spp. and root invading nematodes. This is an ongoing area of research and bioprotection maybe the primary role for AMF in some natural ecosystems rather than nutrient acquisition. This role played by the fungi in increasing a plant’s tolerance of root pathogen attack is a benefit of the mycorrhizal relationship even in a situation where the levels of nutrient and water are adequate.

There are other observations showing how the fungal hyphae provide a surface for soil bacteria to use as a niche, the so-called ‘mycorrhizosphere’. The production of these ‘natural biofilms’ on the surface of hyphae may also play an indirect role in influencing pathogen levels, as well as in aiding nutrient acquisition and improving soil stabilisation.

**Alleviation of environmental stress**

The role played by mycorrhizal fungi in alleviating drought stress in plants has been investigated and the fungi have been shown to enhance drought resistance. The useful application of this is not only limited to arid or semi-arid zones of the planet but also where short-term droughts occur (e.g. east of England), as well as environments where drought stress can be as a result of man-made engineering work.

In more recent years, the potential role of AMF in helping to increase a plant’s tolerance of heavy metals and for the restoration of degraded natural ecosystems has been investigated. Work on heavy metal tolerant strains of AMF, isolated from polluted sites, has provided evidence for their rapid adaptation to contaminated soils, with the pollutant being contained within the mycelium and not transferred to the plant.

An example of the use of mycorrhiza fungi in an inhospitable and harsh environment is provided by some trials conducted in 2000 by Christ Church College Canterbury, in association with PlantWorks Ltd on the Betteshanger Colliery shale deposits in Kent. Here, birch trees were planted directly into the shale: those treated with mycorrhiza showed a reduction in mortality from 60 per cent on the control plots to three per cent on the treated plots. (PlantWorks’ own data).

**Increased nitrogen fixation**

The tripartite interactions between nodulating plants and AMF with the nitrogen-fixing rhizobium bacterium frequently result in increased nodulation and nitrogen fixation as the result of improved P nutrition in infertile or P-fixing soils. This is the result of the high P requirements of the plant and the nitrogen fixing bacterium. The P supplies the high energy required to split the triple bond in atmospheric N. Recent work has shown that specific AMF and rhizobium can interact on the same plant to produce enhanced growth and development in trees with the rhizobial association.
Plant diversity and AMF

The below ground diversity of mycorrhizal fungi is a major factor in the maintenance of plant biodiversity and in ecosystem stability and function. Mycorrhizal fungi can enter the roots of many plant species in the same community resulting in simultaneous colonisation by several species. This results in plants becoming interconnected through the fungal hyphae of each. A survey of the fungal hyphae produced by species from different genera provides indications that each can exploit soil resources in different ways. This network links the root systems of adjacent plants, helping to share, more efficiently, scarce nutrient resources throughout the plant community. In natural ecosystems, young seedlings are able to 'plug' into this extensive network of mycorrhizal fungi, allowing them to survive alongside existing and more aggressive plant species, thus encouraging plant diversity within the environment.

Soil aggregation and AMF

Mycorrhiza formation in soils results in an increased movement of Carbon (C) into roots and the rhizosphere through better root growth and respiration. The hyphae provide a physical structure which can entangle soil particles and lead to micro-then macro-aggregate production. The recent finding, that a glycoprotein called 'Glomalin' is produced by AMF soil-based mycelium and is a major binding agent in soils, adds further weight to the theory that AMF are important in stabilising soils and hence ecosystems.

Strategies for the management of AMF for plant growth

In natural ecosystems, young seedlings can germinate and effectively 'plug' into an already established 'motorway' of hyphae permeating the soil. The lack of host specificity is the secret to the success of AMF in mixed plant communities. To 'kick start' this process in engineered or disturbed environments, to ensure the benefits of the mycorrhizal relationship, mycorrhizal fungi have to be artificially introduced. The most efficient method of achieving this is to 'inoculate' the roots of plants before they are planted out.

The key issue of inoculation, and the beneficial application of mycorrhizal fungi, is how quickly and efficiently the treated plant can become mycorrhizal. Colonisation by mycorrhizal fungi can be successfully achieved by the introduction to the plant root system of root fragments from previously colonised plants, fungal hyphae or fungal spores. The most efficient method of introducing AMF to the root system of plants is through the association with root fragments and hyphae. ECMF, meanwhile, can successfully be introduced using collected spores or mycelium from cultures grown in sterile media.

As many trees and shrubs critically form relationships with both AMF and ECMF at some stage of their life, the products used to treat such plants should logically contain elements of both types of fungi. These elements should be available in the most effective forms to achieve rapid and effective colonisation by both types of fungi — that is they should contain root and hyphal fragments as well as spores.

Commercial products

The philosophy of product formulation differs between companies, but the best products will always be those which can provide large numbers of viable propagules (fungal structures able to colonise plant roots) and which show adaptation to the prevailing environmental conditions. At PlantWorks we call this 'tuning', that is the fungi used in our products have been originally gathered from environments similar to those in which the products are designed to be used, so that they are naturally adapted to those conditions. While ECMF can be highly host-specific, it is our
experience that it is beneficial to incorporate a range of species in our products which are found to associate with most types of commonly used tree, and especially of those pioneer fungi types which form relationships during the early establishment of trees.

The correct mycorrhiza technology, based on a product that has a tuned consortium of fungi comprising all active propagules can be an environmentally harmless and cost-effective substitute for chemical fertiliser regimes. In sites which have been disturbed, mycorrhizal fungi inoculation of all trees and shrubs can reduce plant mortality, promote natural biodiversity and offer a sustainable form of plant nutrition — a single treatment lasting a life time.

References


James Wakeley is marketing director at PlantWorks Ltd, 1/19 Innovation Buildings, Building 1000, Sittingbourne Research Centre, Sittingbourne, Kent ME9 8HL, tel: +44 (0) 1795 411527 < info@plantworksuk.co.uk>