The Role of Arbuscular Mycorrhizal Fungi (AMF) in Crop Phosphorus (P) Nutrition: A Need for Changed Ideas

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RESEARCH

Nutrition

Key messages

- **Arbuscular mycorrhizal fungi (AMF) play an important role in delivering P to crops.**
- **However, determination of the actual contribution of AMF to P uptake by different cereal varieties grown in different soil types is needed, to help understand the apparently contradictory results obtained in different cropping regions.**

Why are arbuscular mycorrhizal fungi (AMF) important?

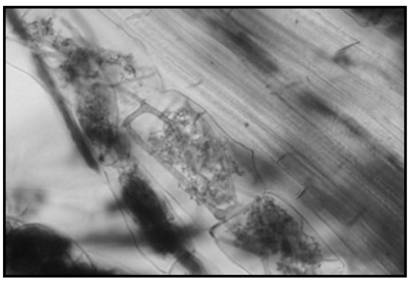
AMF are normal and ubiquitous components of the soil biota. They form beneficial symbiotic associations (partnerships) with the roots of more than 80% of plants, including major field and horticultural crops, as well as pasture species. The activities of fungus and root are closely integrated so that an AM root system is the norm in field conditions. The major exceptions are canola and lupins which do not associate with AMF.

There have been conflicting opinions on the benefits of AMF for cereals. Some research, particularly in the northern Australian grain region, consistently shows marked yield benefits of managing soils and crops to maintain and enhance the extent of AM colonisation of cereal root systems. Other work appears to indicate no benefit of AM colonisation and it has even been suggested that soils should be managed to reduce AMF populations, in order to increase yields. These conflicting views have led to uncertainty of how to manage AMF in field soils and to a situation where much crop research ignores the symbiosis.

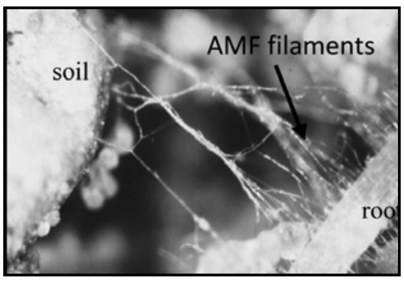
However, new information clearly shows that AMF make very significant contributions to crop phosphorus (P) uptake, regardless of any growth or yield benefits. This means that the AM fungus-plant partnership must not be ignored in research into ways of increasing P uptake efficiency. Such research is critical, because rock phosphate reserves are limited and the price of P fertiliser is rising and subject to both industry and political pressures.

What are AMF?

AMF are one of the biggest contributors to the soil biota and are found in almost all soils, both native and cropped. The AMF grow inside the roots and outside in the soil (Figure 1), forming a critical and highly active link between soil and plants. The natural condition in the field is for plants to be mycorrhizal; this cannot be avoided unless soil is fumigated or sterilised. AMF populations are promoted by minimum tillage and reduced by long fallows, stubble burning and repeat cropping of a non-mycorrhizal crop (e.g. canola). New DNA-based tests are being developed to assess soil populations and ability of the AMF to infect roots. The extent of AM colonisation of roots is often reduced by high applications of P fertiliser. The normal presence of AMF in soils and roots means that it is very difficult to obtain field data on their benefits. Soils have to be fumigated to eliminate or reduce the AMF and provide non-mycorrhizal treatments, but this reduces populations of detrimental pathogens as well as AMF, confounding results of experiments. Most information on function of AM symbioses has had to be obtained from pot experiments under controlled conditions.



AMF structures in wheat roots (blue) growing in soil from Cungena (EP)



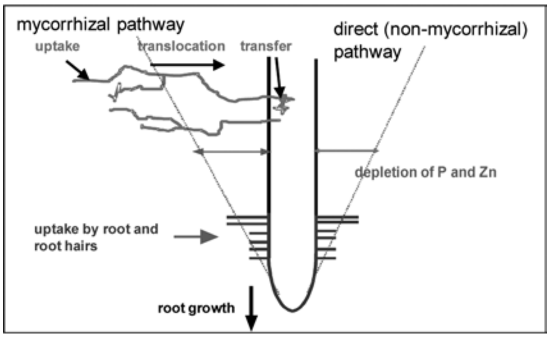
AMF filaments linking roots to soil particles

Figure 1 shows AMF structures (stained blue) inside wheat roots, where nutrients are exchanged and AMF filaments in soil which absorb nutrients. Photos by Lisa Li and Iver Jakobsen

What do AMF do?

Unlike free-living soil organisms which grow on soil organic matter, AMF grow using sugars produced by living plants and in return they deliver nutrients (particularly P and zinc (Zn)) to the plants. Amounts of P have been measured, but amounts of Zn are less clear. The AMF create an extra nutrient uptake pathway (the mycorrhizal pathway - Figure 2) which supplements or even replaces the direct (non-mycorrhizal) pathway. The AM fungal pathway acts like a rapid transit system bypassing the slow movement of nutrients in the soil solution. The hyphae of AMF also help to stabilise soil structure and their activities can improve plant drought tolerance.

Figure 2 shows the two nutrient uptake pathways in an AM root. In the mycorrhizal pathway, fine filaments produced by the fungi (hyphae) grow out from the root, take up nutrients from several centimetres away in soil. Rapid transport through the fungus and transfer to the plant overcome problems of low mobility of these nutrients in soil, which restricts uptake by the direct pathway in plants without AMF. The activity of the mycorrhizal pathway can be tracked using radioactive P isotopes.



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What is new in AM research on cereal P nutrition and growth?

It has always been assumed that the mycorrhizal pathway was 'not working' in plants (like cereals) that showed neither growth benefit nor increased P uptake when mycorrhizal. This led to the idea that AMF could act as parasites by using plant sugars, while not returning any nutritional benefit. This view is now shown to be wrong. New research, some on Eyre Peninsula soils funded by SAGIT and the Australian Research Council, has demonstrated that the mycorrhizal pathway for P uptake is very active in wheat and barley. The AMF delivered up to 80% of total plant P (Figure 3).

The fungi also played a key role in helping the plants to access fluid P fertiliser, as also shown in Figure 2. In a separate experiment it was shown that AMF hyphae could completely replace the activities of roots in P uptake if roots were prevented from accessing the fertilisers. These are very important findings because they show that AMF really are contributing to crop P nutrition. Importantly, research in Denmark showed that the mycorrhizal pathway delivered P to wheat in the field, validating results from pot experiments.

Changed ideas?

AMF play an important role in delivering P to crops. The AMF are not parasitic because they do deliver P in exchange for sugars from the plant. Very importantly, the AMF reduce uptake by the direct pathway and a very small amount of fungus inside the roots can bring this about. Why and how this happens is unknown, but the finding shows that AMF may be playing a controlling role. Another unknown is why AMF have positive effects in some regions of Australia and not in others. The answers most probably lie in differences in responses of crop varieties to local AMF, to the levels and types of P in the soils and in the fertiliser applications. These factors have not been systematically explored.

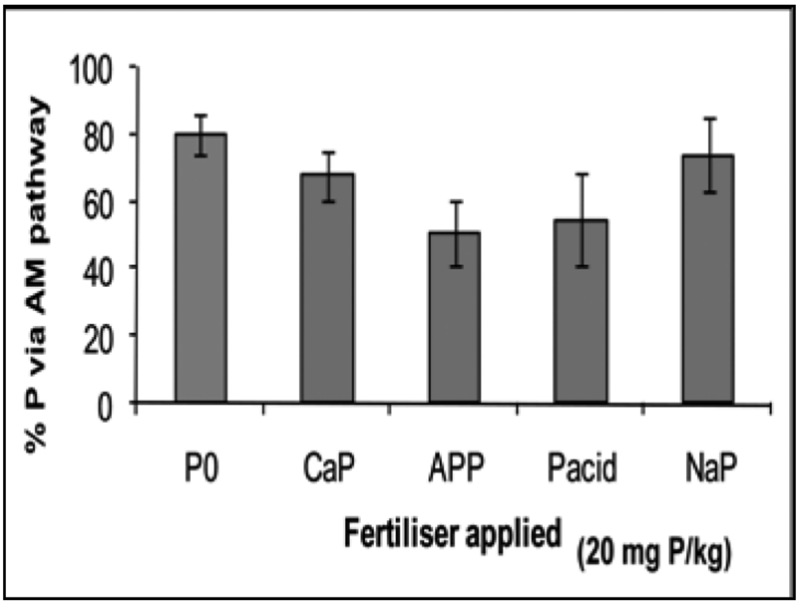

Figure 3 The contribution of the AM fungal pathway to P uptake by wheat grown in soil from Cungena (EP) was between 55 and 80% of the total P in the plants, even though there were no growth benefits, compared with non-mycorrhizal treatments. The activity of the AMF was tracked with 32P. The contribution was highest with no P fertiliser or with added calcium phosphate (CaP), but was still substantial with ammonium polyphosphate (APP), phosphoric acid (Pacid) and soluble sodium phosphate (NaP). The extent of colonisation of the roots was 35-57% of root length, which is high for wheat. Data of Lisa Li.

What is needed now?

Researchers and growers alike need to appreciate that AMF are playing integral roles in root function and P uptake, which are unavoidable because mycorrhizal roots are normal. At the basic level, research is needed to understand how the two pathways for P uptake are integrated and controlled by plant and fungus. A big question is why and how the AMF reduce direct P uptake by the roots but do not always fully compensate for the reduction, leading to P deficiency and poor growth. The knowledge could then be applied in long-term research to manipulate the two P uptake pathways and optimise crop P uptake. At the field level, determination of the actual contribution of AMF to P uptake by different cereal varieties grown in different soil types is needed, to help understand the apparently contradictory results obtained in different cropping regions.

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