Give and take

Drs Heike Bücking, Toby Kiers and Miranda Hart explain one of the most successful symbiotic relationships on Earth and highlight how we must make a greater effort to understand and cultivate this relationship if we are to address the pressing agricultural stresses of our own making.

To begin, can you summarise the key objectives of your research?

HB: The arbuscular mycorrhizal (AM) symbiosis plays an essential role for the nutrient uptake and stress resistance of 65 per cent of all known land plant species, including some of the most important crop species, such as soybean, corn, wheat and rice. Despite its significance, the basis of the mutualistic interaction and the processes involved in balancing resource exchange between plant and fungal partners are still poorly understood. We try to shed light on these processes because in order to use AM fungi in agricultural applications, we need to better understand how costs and benefits of this symbiosis are regulated.

MH: Another goal of our studies is to better understand how non-beneficial partners persist in mutualisms. How can they escape detection and what mechanism allows them to persist in ecosystems? To do this, we look at resource exchange between plant and fungal partners in the AM symbiosis.

How does your project link into the wider biosciences research arena and what do you hope the impact of the research will be?

HB: The AM symbiosis is unique because plants and fungi interact in a common mycorrhizal network through numerous simultaneous interactions. Our studies will help to understand how cooperative behaviour is stabilised in these interactions, how the symbiosis shapes plant communities, and which mechanisms are used by both partners to maximise the benefit from the symbiosis.

MH: In our previous studies, we were able to demonstrate that resource exchange between both mycorrhizal partners is regulated in the form of a biological market, comparable to an economic market. In both, commodities are exchanged between individuals and trading partners are chosen from a number of potential partners. Moreover, those partners providing the greatest benefit are selected in both cases. There is also competition among the members of the chosen class to be the most attractive partner.

TK: While a good deal of theory has been developed on biological markets, this study is among the first experimental demonstrations that these markets are functioning in nature.

What scientific challenges are you addressing through these research activities?

HB: Our past research has focussed on how plants punish their partners when they fail to provide goods or services. Because the fungus cannot exist without a plant host, it has generally been assumed that the plant is in control of the symbiosis. Here we ask whether – and how much – control is exerted by the fungal partner.

MH: In the mycorrhizal mutualism we have a unique situation because not only is the plant associated with many fungal symbionts on a very small spatial scale, but the fungal symbiont also interacts simultaneously with many plants. We try to shed light on whether plant and fungal partner are able to distinguish between good and bad trading partners when these partners intermingle on a very small spatial scale.

At what stage is the project presently?

TK: We have made significant progress since the project started at the beginning of 2011. We currently study resource exchange dynamics in whole plant systems we
developed and will continue to study cost to benefit exchange dynamics under various conditions. Our approach is unique because we are studying these interactions at field scale, whole plant and cellular levels. This fosters a comprehensive understanding of the processes.

**What are the applications of this research?**

**HB:** AM fungi are considered valuable components in agricultural systems due to their role in plant nutrition and soil health. With their positive effect on phosphate uptake, AM fungi could be used to reduce the required phosphate fertiliser inputs in agriculture.

The application of AM fungi could contribute to preserving the worldwide reserves in phosphate rock – a non-renewable resource, whose worldwide reserves are expected to be depleted in 50 to 100 years. The cost of phosphate fertiliser has increased dramatically in the last couple of years, and is expected to increase further. This has increased the expenditures of farmers for fertiliser input, and limits the access to fertilisers for farmers in developing countries. The development of different strategies to increase the fertiliser use efficiency of crops therefore represents an urgent research priority.

**TK:** Mycorrhizal fungi are also incredibly important for global carbon storage. Plants allocate 4-20 per cent of their photosynthetically fixed carbon to AM fungi – this equates with the consumption of roughly 5 billion tonnes of carbon per year by AM fungi.
INTELLIGENCE

COOPERATION AND PUNISHMENT IN THE ARBUSCULAR MYCORRHIZAL SYMBIOSIS

OBJECTIVES

To identify the different scales that stabilise cooperative behaviour in the arbuscular mycorrhizal symbiosis.

PARTNERS

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DR HEIKE BÜCKING received her PhD from the University of Bremen, Germany, in 1995 and her postdoctoral lecturer qualification in 2002. The focus of her research is resource exchange dynamics between partners in ectomycorrhizal and arbuscular mycorrhizal associations.

DR TOBY KIERS received her PhD from University of California, Davis, in 2005 with a focus on ecology, evolution, and agriculture. She uses theory and empirical work to identify factors, such as punishment and reciprocal trade, that helps to stabilise cooperation among species.

DR MIRANDA HART is a microbial ecologist at the University of British Columbia Okanagan. Her primary research focus is on how microbes are distributed in nature, and how humans have altered natural soil communities.

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NEW TECHNOLOGIES

The team is using innovative technologies to tackle these questions. Stable isotope probing – where carbon is ‘labelled’ with a stable isotope that can be differentiated from others present – allows researchers to track the allocation of resources by the host plant to the fungus. Other methods, such as isotope ratio mass spectrometry and liquid scintillation counting, allow precise measurement of carbon in miniscule samples of fungal mycelium.

For some experiments, root organ cultures (ROC) are used, since they allow the direct manipulation of both host and fungus in highly controlled conditions. ROCs offer several important advantages, such as the exclusion of all other microorganisms, the ability to supply plant and fungus separately with resources, with no chance of diffusion and the ease of gathering samples. Essentially, ROCs give the researcher complete control over all factors affecting the interaction, which may not be comparable to natural conditions but still provides an insight into the effect of certain conditions on AM symbiosis.

Additionally, compartment systems with whole plants are used in which the fungal compartment is separated from the root compartment by a divider that allows fungal hyphae to cross but not roots.

SCALING UP

To test their theories under more realistic conditions, the researchers also conduct experiments involving plant and fungal communities. In the greenhouse, the researchers establish different combinations of plant and fungal diversity to test whether the biodiversity of partners affects the ability of a host plant to detect a ‘cheating’ fungus.

This project is being conducted as part of an international programme combining evolutionary theory with practical applications. Results from this experiment will help inform future studies which aim to use AM fungi in sustainable agriculture to improving the nutrient efficiency of crops while decreasing the dependency on chemical fertilisers. The study serves as a model for how scientific work benefits from global perspectives. Indeed, the project is well placed to do so, with one of the project’s Principal Investigators also working as a member of the UN sponsored International Assessment of Agricultural Science and Technology for development, a global initiative evaluating the potential effect of science on global development.

Ultimately the study will greatly improve our understanding of one of the most important symbioses on the planet and provide a framework for determining the benefit of different AM strains. This may have far reaching effect, as the majority of plant communities, including agricultural ecosystems, are dependent on AM fungi. The group will present the results of this research at the ICOM 7, the International Conference on Mycorrhizae, in New Delhi in 2013.