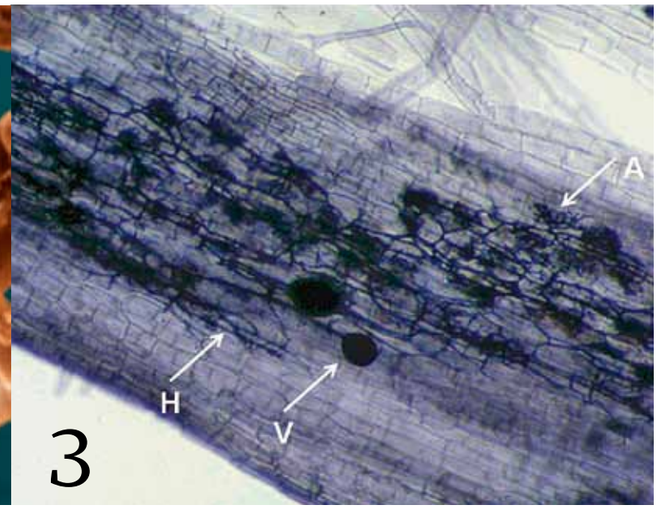

1: RHS / TIM SANDALL; 2: SCIENCE PHOTO LIBRARY; 3: ALAN GANGE

RHS science update

MYCORRHIZAE

Most plants have evolved successful relationships with soil fungi that live on their roots. These mycorrhizal fungi are available commercially to gardeners, but how do they work?

Authors: **Alan Gange,** Professor of Microbial Ecology at Royal Holloway, University of London, and **Robin Sen**, Reader in Soil Microbial Ecology and Biotechnology at Manchester Metropolitan University

1 Many gardeners use mycorrhizal products at planting to aid root establishment and growth. Some rose nurseries now add mycorrhizal fungi to all their stock as a matter of course.

2 Scanning electron micrograph of ectomycorrhizal fungi that form a sheath (orange) over the surface of the roots of many trees and shrubs.

3 Cross-section through a root growing with endomycorrhizal fungi. The fungus actually grows into root cells, forming structures known as arbuscules. H = fungal hyphae, V = vesicles within cells, A = arbuscules.

4 False-coloured scanning electron micrograph showing mycorrhizal hyphae (in yellow) growing on the root of soybean (red-orange).

5 Roots grown in a Petri dish in a lab inoculated with a species of *Glomus*, a common, widespread genus of endomycorrhizal fungi.

Nature's worldwide web

Mycorrhizal fungal hyphae (threads) grow extensively through soil, forming a 'common mycelial network' (CMN). Plant roots 'plug into' the CMN (made up of hundreds, if not thousands of fungi), analogous to the way computers plug into the internet of connected machines.

Remarkable new evidence has shown that plants are able to communicate signals of insect attack to one another via the network, allowing below-ground communication between adjacent mycorrhizal plants. Nutrients can also be passed from plant to plant along the CMN. This places the idea of companion planting in a new light: two adjacent plants of the same species can benefit each other by sharing defence signals; two mycorrhizal plants of different species may share nutrients, while a mycorrhizal plant next to a non-mycorrhizal plant will benefit less from the association.

Adding a suite of mycorrhizal species at planting means greater connection with the CMN that already exists in the soil, and a much greater chance of healthier plants. In nature, three is the average number of mycorrhizal fungi species in a root system, but there can be as many as nine or ten on a single plant.

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Mycorrhizal fungi have become part of gardening practice in recent years, available in garden centres and featuring on television. But what exactly do they do, and are they worth trying at home?

'Mycorrhiza' literally means 'fungus-root', a term coined by German mycologist AB Frank in 1885 when he was searching for a way to cultivate truffles. It describes the intimate association between the roots of plants and a range of different fungi. Fossil evidence from 400 million years ago has shown that these fungi were instrumental in the successful establishment of primitive plants on land. Today, more than 85 percent of land plants form mycorrhizal associations. This benefits both partners, and is an example of a 'mutualistic symbiosis'. Fungi grow into roots and pass mineral nutrients to the plant, which in turn supplies the fungus with sugars that drive the growth of microscopic thread-like fungal strands (hyphae) in a network called a mycelium. The root surface area is effectively expanded more than a million times, allowing the fungus to exploit water and dissolved nutrients locked in soil micropores.

RHS / MARK TIMOTHY

Commercial formulations of mycorrhizal fungi are sold at garden centres.

Garden use

In recent years, commercial products of mycorrhizal inoculum (in the form of dry powder or granules) have become available for gardeners to buy, usually containing several species of naturally occurring fungi. Successfully inoculated plants can become part of a plant community connected by the 'common mycelial network' (see 'Nature's worldwide web', opposite).

There is no question that in controlled conditions such as greenhouses, mycorrhizal fungi provide several benefits to gardeners. Plants grow larger, with more flowers and fruits, and have better resistance both to some pests and pathogens, and stresses such as drought. In situations such as containers and hanging baskets, by enabling roots to make better use of the mineral nutrients in the growing »

Types of mycorrhizae and the plants with which they grow

Most plant families form mycorrhizae with fungal partners, including the rose family (*Rosaceae*), daisy family (*Asteraceae*), peas and beans (*Leguminosae*) and grasses (*Graminae*). Only a small number of plant families do without, notably the cabbage family (*Brassicaceae*), carnations and pinks (*Caryophyllaceae*) and vegetables such as beetroot and spinach (in *Amaranthaceae*).

The mycorrhizal symbiosis is subdivided into **endomycorrhiza** and **ectomycorrhiza**, based on the intimacy of the fungal-root association. In endomycorrhiza, living root cells accommodate microscopic tree-like fungal structures called arbuscules (picture 3). Here, nitrogen and phosphorus are transferred from fungus to plant. Termed 'arbuscular mycorrhizas' (or AMF), these fungi do not produce mushroom-like fruiting bodies, just spores in the soil. They are associated with many garden plants and most food crops.

RHS / BARRY PHILLIPS

Fruiting bodies of fly argaric, an ectomycorrhizal fungus species that grows with trees.

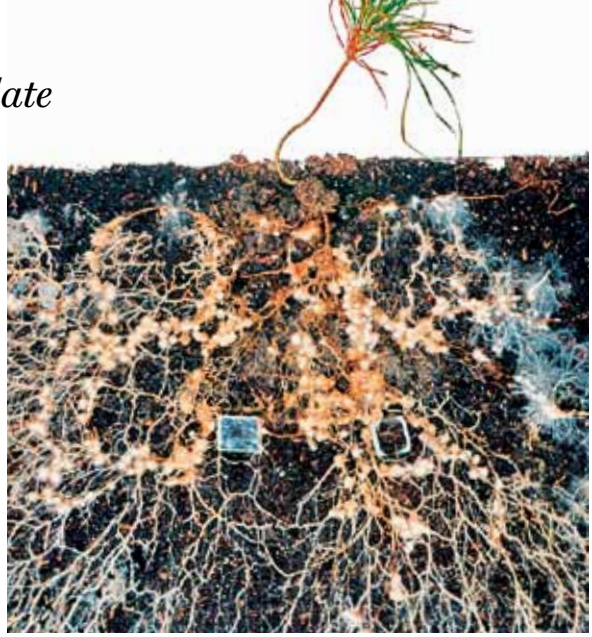
Ectomycorrhizal fungi are mushroom- and truffle-forming species associated with trees and shrubs. Examples include fly agaric (*Amanita muscaria*) and cép (*Boletus edulis*). The fungi form a sheath over root tips and a dense network of filaments (the Hartig net) between root cells. These fungi are more conspicuous in soil, especially those that produce brightly coloured mycelia and rhizomorphs (thicker strands).

How mycorrhizal fungi work

Ectomycorrhizae secrete enzymes that degrade cellulose and lignin, and organic acids, which decompose organic matter such as leaf litter and absorb the nutrients released. The organic acids also degrade rock, making phosphorus and trace elements available to their tree hosts that would otherwise be unavailable.

The bulk of carbon in pine-forest soils has been shown recently to be of mycorrhizal fungal origin. Evidence indicates that arbuscular and ecto-mycorrhizal fungi make plants grow bigger, but can also increase plants' resistance to pests, diseases and stresses such as drought considerably.

Most plant species form just one type of mycorrhiza, but a few (willows, ash and eucalyptus for example) can form both endomycorrhizae and ectomycorrhizae.



ROBIN SEN

The root system of a seedling pine, showing just how extensive root systems boosted by ectomycorrhizal fungi can be, even early in a plant's life.

medium, they can enable plants to produce more flowers for longer.

Often, there can be high levels of a nutrient in a soil, but much may be unavailable to plants. Phosphorus, for example, is fairly immobile in soils as it is chemically bound to particles, so plants cannot access much of it. Mycorrhizal fungi, however, can access these nutrient sources, and supply them to plants – so these fungi can make nutrient use by plants more efficient, reducing the need for manufactured fertilisers.

Managing mycorrhizae

In garden soil, mycorrhizal fungi can work well, but there are certain factors that may reduce their efficacy (see 'do's and don'ts' box, right). Previous application of chemicals – especially fungicides and herbicides – may reduce the chances of the inoculum establishing on roots. An excess of inorganic fertilisers can flood the root system, reducing the amount of fungus the plant needs. Heavy pruning or defoliation of a plant during the growing season can compromise the fungus, too, because the plant has less leaves with which to photosynthesize and thus fewer sugars to feed its fungal partners. Digging soil breaks up the network, and the holes created will take some time to grow back.

When planting trees in gardens, check with the nursery if they have already been inoculated with mycorrhizal fungi. If not, it is worth adding an appropriate product at planting. Mixed inoculants are available for 'dual mycorrhizal' trees (such as willow and eucalyptus), while inoculants of ectomycorrhizae (see box, p47) are ideal for trees such as oak, beech and native conifers.

Most container-grown plants, woody or herbaceous, are grown in composts that contain no (or low) levels of mycorrhizal fungi. If the compost is peat-based this will also reduce the mycorrhizal abundance, as some peats seem to be antagonistic to the fungi. Currently there is interest in using arbuscular mycorrhizae (see box, p47) in peat-reduced or peat-free composts, to provide more efficient nutrient delivery to plants and more even growing media performance.

Most mycorrhizal products contain several fungal species. We know fungi show a degree of host preference: using several fungi means there is a far higher probability of the plant being colonised, so adding a mixture is more likely to produce the fully functioning communities of microbes that we are trying to establish.

In most garden situations, mycorrhizal products should be cost effective – but remember the results will not be as quick as using chemical fertilisers. Adding inorganic nutrients close to roots encourages them to focus on a small volume of soil. Adding mycorrhizal fungi (which you only have to do once) allows a plant to use a far greater volume of soil for its nutrients and water. Growing plants with mycorrhizal fungi may be less instant in effect than fertilisers, but it is a more natural, sustainable way of growing – if gardeners learn to think in seasons, not just in weeks.

Do's and don'ts of mycorrhizal use

✣ Do: always read the instructions on the packet, as not all plants form mycorrhizae (there is no point applying a product to your cabbage or wallflower plants – they are non-mycorrhizal, so nothing will happen). Other shrubs such as heathers and *Rhododendron* form unusual types of mycorrhizae that are yet to be cultured on a commercial basis.

✣ **Don't: apply fungicides in the vicinity of plants that have been inoculated, if possible. All garden fungicides are broad spectrum, and while they are unlikely to eliminate mycorrhizal fungi, they may adversely impact on the fungi's growth.**

✣ Do: remember that you are trying to cultivate a rich soil microbial community. Add compost and mulches, and use organic plant foods that have been specially designed to function with these microbes.

✣ **Don't: expect mycorrhizal fungi to have the same effect on every plant. Ecologists often quantify the 'mycorrhizal dependency' of a plant – this can vary from more or less zero (little or no growth response) to high (inoculation always has a dramatic effect on plant growth).**

✣ Do: think about using the fungi in pots and baskets where nutrients may become limited yet high flower or fruit yield is desired.

✣ **Don't: expect instant results. Sometimes the mycorrhizal benefit may only become apparent later in the season (particularly true with ectomycorrhizae on woody trees and shrubs).**

✣ Do: remember you are trying to cultivate that subterranean mycelial web – think about which plants you grow next to each other. Mycorrhizae may have a big role to play in companion planting, but more research is needed in this area.

RHS ADVISORY

Adding mycorrhizal fungi granules.

SUPPLIERS

✣ **Rootgrow:** supplies a range of formulations to target different plant types and has useful background data on its website. 01795 411527; **www.rootgrow.co.uk**
✣ **www.thenutrientcompany.com**; 01706 358855.
✣ **www.symbio.co.uk**; 01428 685762.
✣ **www.vitax.co.uk**; 01530 510060.
✣ For fertilisers containing mycorrhizal fungi, search 'mycorrhizae' at: **www.dragonfil.co.uk**; at: **www.plantswholesale.co.uk**; and at: **www.viresco-uk.com**

FURTHER READING

✣ **Mycorrhizal associations: the web-resource,** by MC Brundrett, 2008, University of Perth. Visit: **www.mycorrhizas.info/index.html**
✣ **Can microbes feed the world?,** *Microbiology Today* 39 (RHS Chelsea Flower Show Issue, May 2012): 1–111; download from: **www.tinyurl.com/lfhn25v**
✣ ***Mycorrhizal Symbiosis***, by SE Smith and DJ Read, Academic Press, 2008 (3rd Edition), £89, ISBN 9780123705266.