MYCORRHIZAE

SO, WHAT THE HECK ARE THEY, ANYWAY?

by Dr. Linda Chalker-Scott, WSU Science Editor

You've probably seen them before—those white threads too long and slender to be roots, yet intimately associated with the root system of your landscape and garden plants. They are fungal hyphae, and their association with many plant hosts are collectively called mycorrhizae (**myco** = fungus, **rhizae** = roots). These are primitive associations, thought to have arisen hundreds of millions of years ago when vascular plants emerged on land. Originally, mycorrhizal relationships were thought to be unusual oddities; we now know that they are the rule, rather than the exception, especially in woody plants. But, before you grab the fungicide, let's get to know these plant partners.

Mycologists have divided mycorrhizal fungi into two categories depending on how intimate the relationship is: those whose root-like hyphae surround and occasionally penetrate root tissues (**ecto**mycorrhizae; ecto = outside) and those whose hyphae always enter the root cells (**endo**mycorrhizae; endo = inside). Though ectomycorrhizae are only found in a small percentage of plant families, they are important partners of many woody plant species, forming an extensive hyphal network throughout mulch and topsoil layers. (If you use a coarse, woody mulch in your landscape you can easily find fungal hyphae inside the mulch layer and some of these could be mycorrhizal.) In contrast, endomycorrhizae are widely spread through hundreds of plant families and most commonly represented by **arbuscular** (previously called vesicular-arbuscular) species whose hyphal-root interfaces look like branches (arbuscule = small tree) or balloons (vesicle = small bladder). You might find these delicate structures associated with the roots of your annual flowers or vegetables.

How do mycorrhizae infect plants?

Healthy soils contain vast repositories of mycorrhizal spores in the coarse organic matter near the soil surface, where they germinate under moist, aerated conditions. As the hair-like hyphae emerge from the spores, rain- and irrigation water create channels down through the soil towards growing plant root tips. Roots of plants under *mild* nutritional stress release chemical cues, such as organic acids, that stimulate mycorrhizal growth. If the hyphae encounter these receptive roots, they penetrate the cell walls, pressing up into the cell membrane and creating chemical passageways between the two partners. Multiple infection points and hyphal branching create a cottony sheath around the roots that extends far into the surrounding soil.

While inoculated roots tend to be shorter and more branched than uninfected roots, their associated mycorrhizae act like root hairs on steroids, extending far beyond the root mass to exploit soil resources. Like microscopic miners, mycorrhizae discover and extract soil water and nutrients from otherwise inaccessible pockets.

The impact of mycorrhizal colonization goes far beyond an individual plant. Most plants are colonized by a variety of mycorrhizal fungi, and most fungi have multiple hosts. Mycorrhizae can link roots of different species, transferring nutrients to the plants with highest demand. At the same time, the dense network of fine hyphae increase soil aggregates and improve soil stability, while enhancing organic matter decomposition and acidifing the root zone. The resulting network is a virtual fungal freeway of nutrient and water acquisition and transfer.

Mycorrhizal populations are dynamic both in the soil and on plant roots; different species may colonize plants at different times of their life cycle. New mycorrhizal infections can develop from nearby active networks, dormant spores, and even infected root fragments. And when soil conditions are changed by activites as simple as adding organic matter, mycorrhizal species composition changes as well.

Why don't plants have defences against mycorrhizal infection?

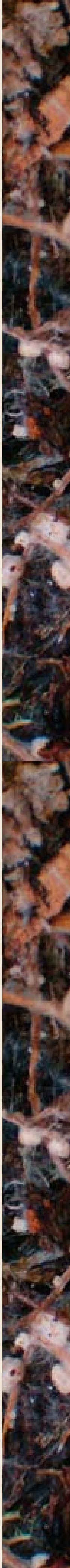
(See "Symbiosis")

Most mycorrhizal relationships are mutualistic ("you scratch my back, I'll scratch yours") in that both partners receive a significant benefit in exchange for sharing resources. Plants transfer carbohydrates and B vitamins through the hyphae to the fungi, which are non-photosynthetic and can't generate their own food. In return, the fungi extensively colonize the root surfaces and enhance the plant's uptake of water and mineral nutrients.

Under well-watered, highly nutritive, crop-producing conditions, there are reports of mycorrhizal parasitism, especially among monocots like wheat or corn whose fibrous root structure is already well-adapted to nutrient uptake. In such unnatural systems, the balance between the partners is shifted so that mycorrhizae take more than they give. Not surprisingly, mycorrhizal parasitism is rarely observed in home gardens and landscapes, where woody plants with coarse root systems have strong mycorrhizal associations.

What are the documented benefits of mycorrhizae on plants?

Mycorrhizae increase both mobilization and uptake of phosphate. This is especially important in alkaline or nutritionally deficient soils, where plant roots have a more difficult time extracting phosphate. Improvements in phosphate nutrition as a result of mycorrhizal colonization have been seen in leafy and



root vegetables, fruits, nuts, grains, and ornamental and timber trees. Mycorrhizae also have a well-documented role in improving

- plant survival and establishment;
- leaf, root and shoot growth;
- fruit/nut/oil yield;
- competition for soil nutrients;
- production of stimulatory plant hormones; and
- nitrogen-fixing activity by leguminous plants.

Mycorrhizae provide economic and environmental benefits as well, reducing both the need for phosphate fertilizers as well as nutrient seepage to the environment.

The trees and shrubs in this landscape, top photo, owe their vigor to what's hiding underneath the protective wood chip mulch. Rake back the mulch to discover healthy brown roots associated with the fine white hyphae of mycorrhizae.

Protection from stress

With the documented benefits of mycorrhizal fungi, it's not surprising to find their plant partners are more resistant to environmental stresses such as drought. A consistent water supply via the mycorrhizal network allows plants to keep their stomates open longer - and photosynthesize longer – than uncolonized plants. Likewise, mycorrhizae can ameliorate salt stress (which also induces drought in plant tissues), an important function in more arid climates.

Since mycorrhizae create a dense fungal network around plant roots, it's not unexpected that colonized plants are more resistant to root pathogens, such as *Verticillium*, and pests, including nematodes.

Not only do mycorrhizae improve the water and nutrient status of plants, making them less susceptible to opportunistic pests and diseases, their physical presence on the root limits the available space for colonization by pathogens.

Mycorrhizae can also protect plants from heavy metal stress (including aluminum, chromium, lead and zinc) by preventing translocation of these toxic minerals from the roots to the rest of the plant. The protective nature of mycorrhizae could allow their plant partners to be used in phytoremediation and restoration efforts at a reduced risk to plant health.

What hurts mycorrhizae?

(See "Phosphate and Mycorrhizae")

Healthy soils, whether in a home landscape or a natural ecosystem, are naturally rich in mycorrhizal species. When the soil chemistry is significantly changed by the addition of pollutants or contaminants including salts, lime, heavy metals, and fungicides, many mycorrhizal species are unable to function. But by far the most damaging to mycorrhizal health is excessive fertilizer application, especially of those containing phosphate; this includes composted manure and many soilless potting mixes. With a plethora of nutrients, plants are less dependent on mycorrhizae, and competitive free-living microbes thrive in nutrient-rich soils. Mycorrhizal fungi retreat into the shadows, remaining inactive until more hospitable soil conditions return.

Any activity that destroys soil structure – like wanton rototilling in a landscape - will also disrupt the intricate mycorrhizal webs beneath the soil surface. Topsoil removal during construction is probably the most damaging of all, as much of the inoculum and all of the organic material and plants are eliminated. Adding insult to injury is the compaction caused by heavy construction equipment, which creates oxygen-depleted soils about as hospitable as cement. Of course, mycorrhizal colonization and

SYMBIOSIS

The Good, The Bad, and Everything In Between

Symbiosis is a general term used to describe the interdependent relationships among species. Three of these relationships—mutualism, commensalism, and parasitism—are divided by the thinnest of fine lines. Understanding how these relationships develop and change over time is both instructive and fascinating.

Parasitism occurs between a parasite and a host, through which the parasite benefits and the host is harmed but not routinely killed. Usually smaller than their hosts, parasites—like aphids, spider mites, or scales—receive food or some other benefit crucial to their survival. The host's resources are partially directed to the parasite at the host's expense. Parasites that kill their host are left without these necessary resources, so the most successful parasites are those that are not lethal. Furthermore, successful parasites avoid alerting hosts to their presence and slip past host defenses. There are good reasons why the saliva of leeches and other bloodsuckers often contains anaesthetizing agents! The various mistletoes, including those used during winter holidays, are well-known examples of parasitic plants.

Some organisms that depend upon a host for survival, apparently neither harm nor help their host. These represent commensal relationships—a good botanical example would be the epiphytic orchids living in rainforest trees. In theory, these orchids cause no damage to their host trees, though arguably an overloaded tree might suffer limb breakage. Some scientists do not believe true commensalism exists, arguing that such close relationships must change the host species in some way. For the sake of this discussion, however, we'll consider commensals to be perfected parasites—they are not organisms that induce a physical or chemical defense from the host.

The best way to ensure a dependent organism's survival is to repay its host—rather than attempting physically or chemically to dislodge the foreign species, the host even invites invasion. Mutualistic relationships confer benefits on both species involved, often to the extent that if one species becomes extinct, the other one's demise is ensured. Many examples of mutualism exist in nature; one of the best studied is the "ant/plant" relationship which includes members of *Acacia*. These trees provide both shelter and specialized food resources for ant colonies, which live in the tree and vigorously attack grazing animals that disturb the host's leaves. Moreover, the ants are weeding perfectionists—they descend the tree and nip off any germinating seedlings that might compete for their tree's water and nutrients.

In my opinion, the most amazing example of symbiosis is found in the cells of plants and animals—including you! We know that chloroplasts and mitochondria both have their genetic origins in primitive single-celled organisms that invaded other early life forms, though the exact process is lost to evolutionary history. Over time, these endo-symbiotic cells became part of their host's biological makeup and vital to host survival. Neither photosynthesis nor cellular respiration could exist without these two organelles, which contain their own circular DNA molecule quite unlike the double helix found in the chromosomes of more complex species. ■

plant communities will eventually recover, but unnecessary soil disruption should be avoided.

What types of activities or products can help mycorrhizal establishment in landscapes?

(See "Practical Information")

To encourage these hard-working and beneficial fungi in your plant community, you've got to cut down the junk (plant) food - stop using soluble phosphate fertilizer! If soil tests show you've got too much phosphate already, research has found that conservative additions of nitrogen fertilizer or organic material can increase mycorrhizal infectivity. Warm temperatures and daylight favor mycorrhizal colonization, as does mild drought or nutrient deficiency. Plant roots need to be receptive to infection, and the best way to ensure this is to avoid overwatering and overfertilization. Other environmentally friendly practices, such as reducing pesticide use and tilling while increasing the diversity of plant materials will favor increased numbers and biodiversity of mycorrhizal species.

Phosphate and Mycorrhizae: A Love/Hate Relationship

One of the many benefits of mycorrhizal colonization is that plant root uptake of phosphate—especially "unavailable" forms—is greatly increased. Yet numerous studies have demonstrated that phosphate fertilizer is deadly to mycorrhizal associations. How can these two realities coexist?

When a plant senses that its tissues or the soil contains enough phosphate, it no longer needs its mycorrhizal partner and so becomes less receptive to infection by mycorrhizal spores. Phosphate amendment—especially soluble forms—will inhibit mycorrhizal development on many economically important plants. In non-agricultural systems, such as grasslands, wetlands, and forests, phosphate addition has a similar inhibitory effect on mycorrhizal infection. This negative interaction has been experimentally demonstrated and repeated in laboratories, greenhouses, nurseries, fields, forests, and managed landscapes.

Often this inhibition is an issue of moderation. High levels of soluble phosphate nearly always squelch mycorrhizal activity, while lower levels are sometimes syngergistic with mycorrhizae, especially if phosphate is unavailable due to soil alkalinity. One form of this mineral—rock phosphate—can be particularly difficult for plant roots to mobilize. Mycorrhizae, however, can easily solubilize this mineral and transport it to the plant roots. Since plant roots perceive a lack of available phosphate, they are receptive to mycorrhizal infection and subsequent uptake of this phosphate source.

But, as with any other fertilizer, rock phosphate should never be added to a landscape unless soil tests indicate a nutrient deficiency. ■

Do mycorrhizal amendments work in landscapes?

Mycorrhizal amendments are heaviy marketed as products that will improve soil health and plant establishment in gardens and landscapes. These products can be effective for inoculation of sterilized container media, but scientific studies on urban landscapes and other "real world" systems report that these products have no significant value. In general, plant species inoculated with commercial products and installed into the landscape are equal in performance to uninoculated controls (which quickly became colonized with native fungi). While the addition of organic matter has been found to stimulate growth of native mycorrhizal populations, applying commercial mycorrhizal amendments is generally ineffective and unnecessary, given the widespread presence of indigenous inoculum.

One recent study tested several commercially available products containing mycorrhizal fungi and various so-called "biostimulants" (e.g. kelp, humic acids, and yucca plant extract) on the establishment and survival of four commonly used ornamental trees and shrubs. In the researchers' words, "the treatments did not lead to a significant improvement of plant growth of transplant survival compared to the untreated plants receiving routine mulching with pine bark mulch alone."

From a practical standpoint, two realities emerge from all the research done thus far:

- Healthy soils naturally contain indigenous mycorrhizae. Adding packaged mycorrhizae to such soils is a waste of money and resources.
- If soils are impaired to the point where indigenous mycorrhizal species can't survive, mycorrhizal amendments alone won't help.

Beneficial microbes are important components of garden and landscape soils, and the best way to cultivate their presence is through thoughtful, sustainable horticultural practices. ■

PRACTICAL INFORMATION for cultivating mycorrhizae

Coarse organic mulch is good reservoir for spores, and litter type affects mycorrhizal diversity. Try to use a mixed mulching material, such as arborist wood chips, which will help reduce nutrient runoff and leakage.

Living mulch can facilitate mycorrhizal networks between plants. Consider using some of the many low-growing, drought-tolerant ground covers available commercially.

Beneficial bacteria can assist in mycorrhizal activity. Eliminate unnecessary use of broad-spectrum bacteriocides.

Diverse landscape plantings favor mycorrhizal diversity. Use a variety of trees, shrubs, ground covers, herbaceous perennials, bulbs, and annuals.

Strongly mycorrhizal plants—those with coarse root systems—can alleviate phosphate overloads in landscape soils and enhance mycorrhizal diversity. ■