

Mycorrhizae

in the Alaska Landscape

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Mycorrhiza (pronounced Mike O’Ryza) is the name of the very important relationship between plant roots and certain types of fungi. Unlike the fungi that cause diseases, the mycorrhizal relationship benefits both the host plant and the fungi. The plant provides the fungi with carbohydrates and, in exchange, the fungi increase the plant’s ability to take up phosphorus and micronutrients from the soil and provide protection from certain root diseases. It also improves the plant’s ability to access water from the surrounding soil, which helps keep the plant hydrated in dry soil conditions. Although it is most common to find mycorrhizal associations in Alaska’s perennials, mycorrhizae are also found in many annual crops.

Over 95 percent of the plant families are known to have some form of mycorrhizal associations, particularly in undisturbed conditions. In fact, this relationship is so common, evidence of its existence has been found in fossils dating back 460 million years. Understanding how mycorrhizae operate in natural systems may be beneficial to improving the quality of plants in our gardens and landscapes while minimizing the need for fertilizer and water.



Ectomycorrhizal short roots (root tip mycelia of the Amanita” type).
Source: www.biomedcentral.com/1471-2105/6/178

Mycorrhizae in the Annual Garden

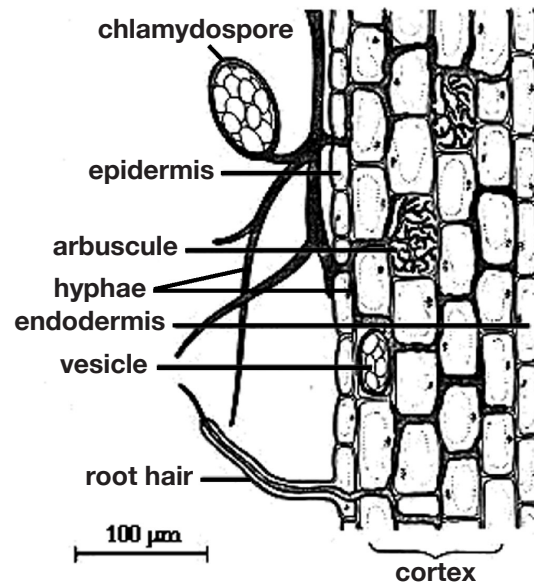
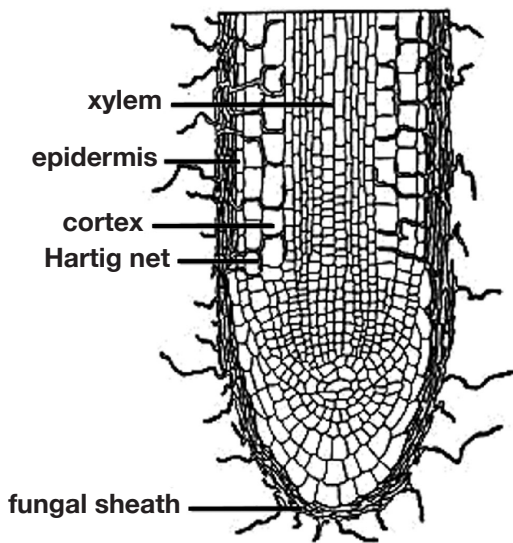
Although mycorrhizal relationships are generally associated with perennials, AM fungi are shown to increase the growth and nutritive status of virtually every important annual (or biennial) agronomic crop in the United States except the Brassica family of vegetables (broccoli, cauliflower, kale, cabbage and Brussels sprouts).

What are Mycorrhizae?

The word *mycorrhizae* comes from two Greek words, *mycos*, which means fungus, and *rhiza*, which means root; therefore, mycorrhizae literally means “fungus root.” The term mycorrhizae is often used as if referring to a type of fungi, but the term actually refers to the relationship between the fungi and the host plant’s roots. Several sources imply that it is a single fungal species that forms these mycorrhizal relationships when in reality approximately 2,000 different species of fungi are known to form these relationships.

There are two main types of mycorrhizal relationships: **ectomycorrhizae** and arbuscular **mycorrhizae**.

The **ectomycorrhizae** (ECM) association is specific to roots of trees such as birches, willows, pines, oaks and spruces. The fungi physically connect with the roots of the host plant, improving the plant’s ability to take up water and nutrients. They also form a sheath, or mantle, around the root, which physically protects the root from some types



Ectomycorrhize (left) form a sheath, or mantle, around the root to improve the plants ability to uptake water and nutrients. Arbuscular mycorrhize (right) facilitate water and nutrient uptake with hyphae that enter plant cells to facilitate water and nutrient uptake.

of disease-causing fungi. Many of the ECM fungal species can be cultivated in the laboratory and are commercially available. A list of trees and their fungal partners can be found in *The Container Tree Nursery Manual* at www.rngr.net/Publications/ctnm.

The **arbuscular mycorrhizae (AM)** relationship affects both perennials and annuals. The main difference between the AM and ECM relationship is that the AM relationship does not create a protective mantle around the root the way the ECM does. Instead, its hyphae enter the plant cells, producing structures that facilitate water and nutrient uptake by the plant. One way to spread AM fungi is to collect root tissue and the soil immediately surrounding the root from a host plant that is known to have the AM fungi and incorporate it into the soil of the new plant. Management of arbuscular mycorrhizae focuses on maintaining soil conditions favoring the fungi rather than constantly adding more fungicolonized tissue to the host plant. Establishing a successful mycorrhizal relationship can be difficult because some of the species of fungi may be site specific.

What are the benefits of the mycorrhizal relationship to the plant?

- Increased absorption of nutrients and water:** Plants absorb nutrients and water through their fine root hairs; the mycorrhizal relationship increases the amount of nutrients and water the plant can absorb by providing fungal hyphae, which function in a similar way. The fungal hyphae, however, have three advantages over the plant's root hairs: 1) the hyphae reach farther out into the soil, covering more area than the root hairs, 2) they are more attracted to nutrients than root hairs, and 3) they are smaller than root hairs, so they can get into spaces in the soil that the root hairs cannot. Researchers have measured between 7 and 8 miles of mycorrhizal hyphae in about a teaspoon of soil; these hyphae increase the amount of soil the plant can access by up to 100,000 times.
- Increased phosphorus uptake:** Hyphae promote the growth of bacteria that can extract phosphorus from organic matter. The phosphorus released by the bacteria is absorbed by hyphae and passed on to the plant. This is the most well-known nutrient benefit, but the hyphae also

increase the plant's uptake of potassium, copper, iron, nickel, sulfur and zinc.

- **Increased establishment and capacity of nitrogen-fixing nodules in legumes:** The increased uptake of phosphorous that is characteristic of a mycorrhizal relationship particularly helps legumes, such as peas, to fix nitrogen. Phosphorous enhances the colonization of the *Rhizobium* bacteria within the plant roots. These bacteria use nitrogen from the air and convert it into forms that the plants can use.
- **Root disease suppression:** Mycorrhizal relationships protect host plants from disease both chemically and physically. The fungi produce antibiotics that inhibit disease organisms and further suppress diseases by improving host nutrition, which increases plant vigor. Healthy plants are better able to resist or tolerate pathogens such as *Fusarium*, *Rhizoctonia*, *Phythium* and *Phytophthora* (all root-rots) and *Verticillium* (a stem disorder). Also, the protective sheath, or mantle, formed by the ECM relationship physically protects the root from disease.
- **Increased production of plant growth hormones:** Mycorrhizal colonization often increases levels of cytokinins and gibberellins, which are plant hormones responsible for cell division, stem elongation, seed germination and other functions.
- **Limited protection against high soil concentrations of heavy metals:** The fungal hyphae block the plant's uptake of zinc, cadmium and manganese from soil with excessive levels of these nutrients. This protection for the plant roots enhances the plant's ability to revegetate and stabilize the soils of reclaimed mines that may be high in heavy metals.
- **Enhanced the soil's physical characteristics:** Compounds like glomalin, a carbohydrate/protein molecule, are excreted by fungal hyphae and act like glue, causing soil particles to stick together, or aggregate. Soil aggregates are resistant to breakdown by water and enhance the soil's physical characteristics, such as water and

Collecting Source Soil

Since the fungi that establish the AM relationships cannot be grown in a lab, the best way to inoculate plants with these types of fungi is by using source soil. Source soil is collected from beneath a known host or related species, and includes spores, fungal hyphae and host root material from the original plant. The source soil should be collected in a location that has not been cultivated in the past few years or treated with excessive phosphorus fertilizers or soil fumigants, because these conditions inhibit development of mycorrhizal associations.

Collect about 12 ounces of soil and roots, going down about 4 inches below the plant. It is important not to collect too much from a single plant in order to ensure the plant's continued survival. Keep the sample cool and relatively dry, and use as soon as possible to ensure best results.

It is important to remember that the soil sample is not sterile. It may actually contain pathogenic bacteria or fungi such as *Pythium* or *Phytophthora*, which may be accidentally introduced to the garden. If there are any negative effects on the plants in the garden after inoculation with source soil, it is a result of pathogenic organisms, not mycorrhizal fungi.

air movement in the soil. The fungal hyphae also physically hold nonaggregated soil particles together, allowing other bacterial and fungal compounds to form these particles into aggregates. These aggregates are important for the soil food web.

How do we determine if a plant has an existing mycorrhizal relationship?

It can be difficult to determine if the sample you are interested in has a mycorrhizal relationship, and many of the manufactured topsoils purchased in Alaska initially lack the fungi necessary to create mycorrhizal relationships. The easiest way is to determine whether or not the mycorrhizal relationship is there is to ask the nursery or landscaper if they are using growth media with mycorrhizae or if they have inoculated the plant's roots. Another way to determine if the relationship is there is by physical identification. With the appropriate training, it is possible to identify the root mantle and branched

club-shaped roots often associated with ECM, but other mycorrhizal relationships are identified using stained roots and high-powered microscopes. Determining the presence of mycorrhizae is usually a destructive process, which means at least a subsample of host roots will be damaged. There are laboratories out of state that will identify mycorrhizae, but they can be expensive.

In general, little harm will come from inoculating a plant that has an existing mycorrhizal relationship (other than spending some additional time and/or money); therefore, it may be better to just assume that the new plant does not have a mycorrhizal relationship.

Commercial Inoculants

Commercial inoculants are available for use on trees such as birches, willows, pines, oaks and spruces. As previously mentioned, the fungi involved in ECM relationships can be cultivated in a laboratory; therefore, they can be commercially obtained. It is important to do some background research before purchasing any inoculate fungi to make sure it is the appropriate fungi for the tree that is being inoculated, and it is important to follow the manufacturer's instructions regarding how to use the inoculate.

Since the fungal species that establish AM relationships can not be grown in a lab, some vendors sell ground roots of hosts already inoculated with mycorrhizal fungi. However, it is unknown that any successful mycorrhizal relationships using these commercially prepared AM inoculants have been established under Alaska growing conditions.

There are a number of companies that sell commercially produced inoculants. In general, these companies sell one of two categories of inoculates: a "one-size-fits-all" cocktail of different species of fungi and a collection of inoculates "tailored" to the soil environment in which it will be used. Of these two categories, the one to be most skeptical of is the one-size-fits-all cocktail because it simply contains a plethora of fungal species in the hopes that one will be the appropriate species to fit the soil environment and plant species it is intended for.

Inoculation with Mycorrhizal Fungi

Natural spread of mycorrhizal fungi back into soil can take several years — too long to be beneficial to current gardens and plants, or even to those planned for the near future. AM fungal spores are large and heavy, so they must rely on the same forces that move soil, such as strong winds, water, gophers and worms, to migrate to a new location. ECM fungal spores, on the other hand, are extremely small and are readily transported on wind or water; however, the ECM fungal species are host species specific and might not travel to the appropriate locations right away.

Since natural inoculation takes so long, home inoculation with mycorrhizal fungi is recommended. Inoculation of plants that already have a mycorrhizal relationship should have no negative effects on the plant, nor should adding inoculant of a fungi species that is not compatible with the plant species. Even if an inoculation is unsuccessful in establishing a mycorrhizal relationship, it shouldn't harm the plant.

When inoculating plants, the very first and most important decision to make is whether to buy commercially available inoculants or to collect source soil for inoculation. After deciding which source of inoculation is best, place the inoculant where the germinating seed or transplant roots have the greatest chance of hitting the source soil — with its fungal inoculum — in the shortest amount of time. The inoculation process is not unlike producing a "sourdough starter," where you are using a little starter in the hopes that the organisms will colonize your new transplant.

Studies have shown that concentrating fungi around the anticipated location of the roots is more effective than spreading the inoculum throughout the pot and allows the gardener to use less fungal inoculum.

What practices hurt mycorrhizae in the soil?

- **Fallow situations:** AM fungi form a symbiotic relationship with the host plant and depend on that relationship for survival, so any process that disturbs living roots in the soil will be destruc-

Difficulty Establishing AM

The species of fungi that form AM relationships are not host-specific; however, research indicates these fungi can be site-specific. The physical, chemical and biological properties of the soil from which an AM fungus was collected may be very different from garden soil. In this case, garden plants may not display the anticipated growth benefit from inoculation.

For example, a study compared the growth response of pigeon pea when inoculated with two different sources of the same AM fungal species (*Glomus deserticola*), one from Utah and one from California. The Utah isolate resulted in pigeon pea foliage and roots that were 2.5 times the size of the California isolate. This result implies that soil conditions are significant to the survival of the mycorrhizal fungi.

tive to mycorrhizal fungi. If soil remains for a long period of time without suitable hosts for the mycorrhizal fungi, the fungal population will decline.

- **Frequent and/or deep tillage:** The plant-fungi relationship can be damaged by soil disturbances. The majority of mycorrhizae reside in the top few inches of the soil, and plowing or excessive rototilling pushes much of the mycorrhizal fungi below the level where the roots grow. These disturbances can also expose the organisms to the sun's damaging ultraviolet rays.
- **Heavy fertilization with phosphorus:** With high levels of phosphorus in the soil (above 100 parts per million) in a form that plants can use, the roots don't need help from the mycorrhizal fungi to take up the phosphorus. When levels are less than about 50 parts per million, the fungi play a key role in improving the plant's ability to take up phosphorus. Thus, heavy fertilization with phosphorus makes the fungi unnecessary to the plant, so the plant has no advantage in helping to help keep the fungi alive.
- **Lack of plant diversity:** In locations where only one species of host plant is available, the mycorrhizal fungal community can shift toward favoring fungal species that are effective for the available host plant. Consequently, when intro-

ducing a new crop into this environment there will likely be fewer species of mycorrhizal fungi able to associate with it. Ultimately, a mycorrhizal population is enhanced by a diversity of host plants, including weeds.

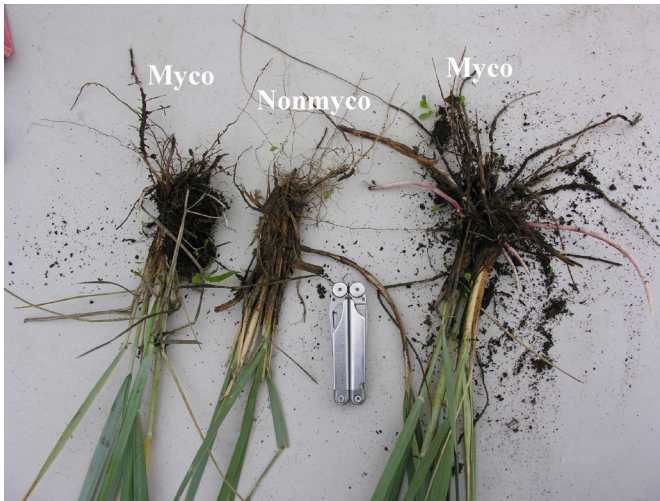
- **Excessive heat from fires:** Since the majority of mycorrhizal spores are near the soil surface, burning material in one place can heat the soil enough to kill the fungi. Therefore, a slow-moving forest fire can cause more damage to the fungi than a quick-moving fire. If a gardener decides to burn leftover plant material rather than turn it into compost, it would be most beneficial to the fungi to burn the materials in a location away from the garden.
- **Water-logging:** Mycorrhizal fungi require oxygen to survive so they do not do well in water-logged soils because there isn't enough oxygen.

Composting and Mycorrhizal Fungi

Despite the claims of many composting websites, mycorrhizal fungi will most likely not survive the composting process. The hot composting process involves high moisture levels and high temperatures, conditions that the fungi would likely not survive. Furthermore, the fungi would not likely survive in cold-composted material because it would not have a suitable host.

Compost Teas and Mycorrhizal Fungi

The process of making compost tea involves steeping high quality compost in highly aerated water, and mycorrhizal fungi would not likely survive the process. AM fungi exhibit very limited growth independent from their host plant, so they would likely not survive in a bucket of compost tea without access to a living host. Furthermore, AM fungi are root-colonizing organisms that thrive underground and away from sunlight, so application by spraying compost tea on plant leaves or the surface of the soil does not put the fungi in close enough contact with the plant roots for fungal survival. All of these characteristics would, ultimately, inhibit survival of mycorrhizal fungi in compost tea and make it an unsuitable method of inoculation.



Root balls from non-inoculated samples of 'Reeve' beach wildrye plants were smaller than root balls from plants inoculated with mycorrhizal fungi.

However, the mycorrhizae association has been observed in rice paddies, suggesting that at least some species of fungus may work in a low oxygen environment.

- **Fungicides:** Some fungicides can be harmful to mycorrhizal fungi, but it all depends on the type of fungicide used. Fungicide that is applied to the leaves and branches of plants has little effect on mycorrhizal fungi since the fungicide doesn't contact the roots. On the other hand, systemic fungicides, which are transported through the roots, can have major effects on the mycorrhizal fungi. Furthermore, seeds treated with fungicide may not be harmful, but that depends on the species of plant. Some fungicides, like metalaxyl,



'Reeve' beach wildrye plants inoculated with mycorrhizal fungi showed more vigorous growth than those not inoculated with mycorrhizal fungi.

actually stimulate mycorrhizae colonization by eliminating fungal competitors. Most herbicides and insecticides applied at the recommended rate have little impact on the mycorrhizal population.

Examples of crops improved by mycorrhizal fungi in Alaska

Legume:

An on-farm trial of snap peas in the Mat-Su District showed increased growth for peas inoculated with mycorrhizal fungi. The peas were seeded in a greenhouse and transplanted to the field in early July. One set of transplants was inoculated with a half teaspoon of Mycogrow™ for Vegetables (a commercial mycorrhizal inoculant), and the other was simply transplanted. All plants were harvested in early October to determine their potential as a soil-building cover crop. In general, the inoculated plants were approximately 10 percent taller than the non-inoculated plants.

Other types of mycorrhizal relationships

Orchid mycorrhizae: The over 20,000 species of orchid benefit from a mycorrhizal relationship, including house plants and Alaska's bog orchid.

Arbutoid mycorrhizae: Found in California's chaparral plants.

Ericoid mycorrhizae: Primarily associated with acid-loving plants, including *Vaccinium*, the blueberry genus and possibly one of the most prevalent forms of mycorrhizae in Alaska given the diversity of berries across the state.

Grass:

A field trial involving 'Reeve' beach wildrye plants on the Alaska State Fairgrounds in Palmer revealed more vigorous growth in inoculated plants than in those not inoculated with mycorrhizal fungi. Wildrye plants in 9-inch pots were transplanted into the field, some inoculated and some not. The inoculated plants showed a striking difference in plant size the following year, and there were noticeable differences in the root balls and surrounding soils of those plants. The non-inoculated plants were smaller and the root balls fell apart when the plants were removed from the test plots. The soil aggregates from the root balls of the inoculated pots were twice as stable as the aggregates from the non-inoculated root balls. These findings help to illustrate the role of mycorrhizal fungi in building soil structure and improving the soil quality in the garden.

Revegetation:

In a revegetation trial at a Southcentral coal mine, balsam poplar and American greenleaf alder seedlings were transplanted either with soil from neighboring mature forests (expected to have high amounts of mycorrhizae) or with soil from neighboring immature forests (expected to have low amounts of mycorrhizae). Two years after transplanting, the balsam poplars with the mature forest soil were 20 percent taller than the balsam poplars with the immature forest soil. Furthermore, in the alder plots, trees with the mature soil treatment were 40 percent taller than those with the immature forest soil treatment.

Summary

As we've seen, mycorrhizae is a very important relationship for plants in the Alaska landscape. A better understanding of the biology involved will help gardeners successfully establish mycorrhizal relationships and identify some of the hype generated by various commercial interests.

In recent years fertilizer costs have increased three- to fourfold. Volatile fertilizer costs may become the norm as the U.S. has to compete with the world market for natural gas resources, one of the raw inputs for industrial nitrogen fixation. With some studies showing that mycorrhizal plants grow three times larger with one-third the amount of fertilizer (in low P soils) compared to their non-mycorrhizal counterparts, and other studies indicating that symbiotic nitrogen fixation increases tremendously when adding mycorrhizal fungi and Rhizobia, thus reducing the amount of nitrogen fertilizer needed, mycorrhizal plants may prove to be a cost effective means to counter the rising cost of fertilizer.

Natural systems indicate that *mycorrhizae are the rule and not the exception*. By using principles common in nature we can learn to grow more sustainably.

For more information, contact your local Cooperative Extension Service office or Jeff Smeenk, Extension Horticulture Specialist, Agriculture and Horticulture, at 907-746-9470 or jeff.smeenk@alaska.edu. Reviewed by Stephen Brown and Robert Gorman, Extension Faculty, Agriculture and Horticulture, and Jodie Anderson, Instructor, School of Natural Resources and Agricultural Science.

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