A GARDENER'S PRIMER TO MYCORRHIZAE: UNDERSTANDING HOW THEY WORK AND LEARNING HOW TO PROTECT THEM

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Overview

Mycorrhizae are symbiotic associations between many plants and the beneficial fungi that colonize their roots. Gardeners are often unaware of these relationships and may inadvertently injure or kill the beneficial fungi through common gardening activities. This publication will help home gardeners understand the benefits of mycorrhizae and explain how to enhance their presence in landscapes and gardens.

Introduction

Mycorrhizae are associations between some fungal species and the roots of many host plant species (Figure 1). The word mycorrhizae reflects this partnership:

myco = fungus

rhizae = roots

These are primitive associations which developed 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.

Mycorrhizal fungi are divided into two categories: those whose root-like hyphae surround and occasionally penetrate root tissues (ectomycorrhizae) and those whose hyphae always enter the root cells (endomycorrhizae). Ectomycorrhizae colonize the roots of many woody plant species and form an extensive hyphal network throughout mulch and topsoil layers. Because ectomycorrhizae are commonly found on tree and shrub roots and are the easiest for gardeners to see, this publication will use them as general examples.

Figure 1. A mycorrhizal partnership between a fungus and a plant root.

The Benefits of Mycorrhizal Relationships

The relationship between plants and mycorrhizal fungi is mutually beneficial. Plants are photosynthetic and provide sugars, B vitamins, and other important chemicals to their fungal partners. Fungal hyphae are long and thin and can better explore the soil for water and nutrients compared to plant roots. Mycorrhizae are particularly adept in extracting phosphate from the soil. Phosphate is often immobile in soils, and mycorrhizae are able to solubilize phosphate in their immediate environment (Badawi 2010). Phosphate and other nutrients and water are shared with the plant through the mycorrhizal relationship.

Increased water and nutrient uptake allow plants to establish faster, grow bigger, and survive longer than plants without mycorrhizae. Healthier plants are more resistant to environmental stress, pests, and disease. This is especially evident with root pathogens. Mycorrhizal plants are more resistant to diseases such as *Verticillium* (Garmendia et al. 2004; Whipps 2004) and pests, including nematodes (Affokpon et al. 2011; Verma and Nandal 2006).

In comparative studies, mycorrhizal plants had increased tolerance to drought (Auge 2004; Walker et al. 2003), salt, and heavy metals such as zinc and lead (Ma et al. 2006). Mycorrhizae can help prevent uptake of these toxic minerals from soil (Meharg 2003) and inhibit their movement from the roots to the shoots (Chen et al. 2005).

Mycorrhizae provide economic (Al-Karaki 2002) and environmental benefits as well. Because mycorrhizae increase uptake of essential nutrients (Ma et al. 2006), there is less need for fertilizers (Hamel and Strullu 2006; Sharma and Alok 2004). Mycorrhizal networks are also credited with reducing excess soil nutrients from seeping into aquatic ecosystems (Hamel and Strullu 2006; Liu et al. 2004).

How Mycorrhizal Fungi "Infect" Plants

Mycorrhizal spores lie dormant in coarse organic matter near the soil surface and in the soil itself. Roots of plants under nutritional stress release chemical cues, such as organic acids and strigolactones (Yoneyama et al. 2013), that stimulate spore germination. As the hyphae emerge from the spores, they encounter these receptive roots and penetrate the plant's cell walls (Figure 2). Ectomycorrhizal fungi inoculate roots at several points, creating a cottony sheath around the roots that extends far into the surrounding soil.

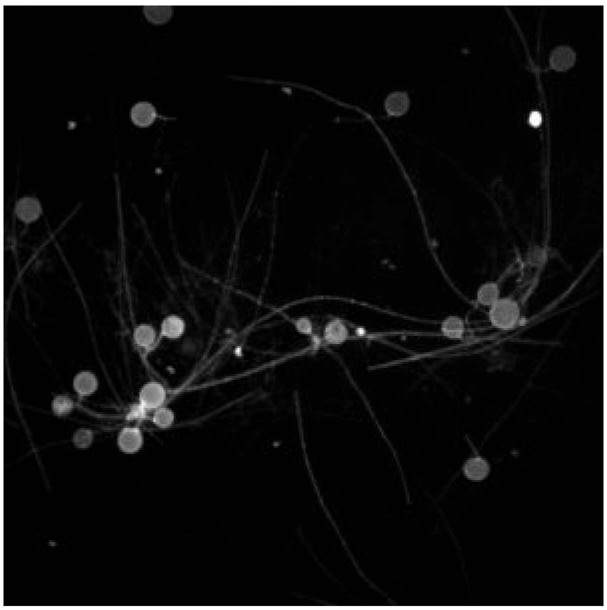

Figure 2. Germinating fungal spores.

With their associated mycorrhizal fungi acting like elongated root hairs, plants do not need to expend energy growing their own exploratory roots. Roots inoculated with ectomycorrhizal fungi are shorter, less numerous, and have fewer branches than uninfected roots (Wiseman and Wells 2009) (Figure 3). Mycorrhizal hyphae can extend beyond the root mass to extract soil water and nutrients from otherwise inaccessible pockets.

The impact of mycorrhizal colonization goes well beyond an individual plant. Most plants are colonized by a variety of mycorrhizal fungi, and most fungi have multiple hosts. This dense network of fine hyphae increases soil aggregate formation (or "clumping") and improves soil stability (Cavagnaro et al. 2006; Kohler et al. 2006; Liu et al. 2006), while enhancing organic matter decomposition and acidifying the root zone.

Figure 3. Shortened pine roots covered in fungal hyphae.

How Mycorrhizae Can Be Inhibited or Injured

Significant changes in soil chemistry and structure can injure mycorrhizal networks. By far the most damaging to mycorrhizal health is the use of unnecessary fertilizers, especially those containing phosphate (Azcon et al. 2003; Berch et al. 2006; Breuillin et al. 2010; Cheng et al. 2013; Grant et al. 2005; Shukla et al. 2012; Vivas et al. 2003; Walker et al. 2003). Nutrient-rich organic material, including composted manure (Garcia et al. 2007) and many soilless potting mixes, are also inhibitory if they contain moderate to high levels of phosphate (Linderman and Davis 2003).

When plant tissues, or the soil, contain enough phosphate, the plant becomes less receptive to inoculation by mycorrhizal spores (Breuillin et al. 2010). 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 phosphate nearly always restrict mycorrhizal activity (Grant et al. 2005; Linderman and Davis 2003; Ortas et al. 2002; Sharma and Alok 2004). Low levels of phosphate, especially in intensive agricultural production systems, may be necessary to allow mycorrhizal species to compete with non-mycorrhizal microbes for this nutrient (Raiesi and Ghollarata 2006). 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 (Antunes et al. 2007). Since plants perceive a lack of available phosphate, they are receptive to mycorrhizal infection and subsequent uptake of phosphate (Rubio et al. 2002). But as with any other fertilizer, rock phosphate should never be added to a landscape unless soil tests indicate a deficiency.

In addition to fertilizer overuse, any activity that destroys soil structure, including excessive tilling and cultivation, will also decrease mycorrhizal communities (Antunes et al. 2009; Garcia et al. 2007; Hijri et al. 2006; Figure 4). Topsoil removal during construction is probably the most damaging, as much of the inoculum and all of the organic material and plants are eliminated. Construction also compacts the soil and reduces oxygen, lowering oxygen-dependent mycorrhizal activity; flooded soils experience the same loss (Caravaca et al. 2005; Ipsilantis and Sylvia 2007). Of course, mycorrhizal colonization and plant communities will eventually recover, but unnecessary soil disruption should be avoided.

Figure 4. Rototilling destroys mycorrhizal networks along with soil structure.

Use of Commercial Mycorrhizal Inoculants

Our increased understanding of mycorrhizal influences on plant health has led to an explosion of commercial products for inoculating plants and soils (Figure 5). There has been some success in inoculating sterilized container media used in greenhouse or nursery production (Corkidi et al. 2004, 2005; Kahn et al. 2007), and in repopulating soils that have been fumigated (Blal et al. 1999). However, scientific studies on gardens and landscapes find that mycorrhizal amendments are generally ineffective and unnecessary (Abbey and Rathier 2005; Appleton et al. 2003; Bell et al. 2003; Carpio et al. 2003; Rowe et al. 2007; Wiseman et al. 2009). Given the widespread presence of fungal spores already in the landscape, plants quickly become colonized by native mycorrhizal species (Appleton et al. 2003; Carpio et al. 2003; Cook et al. 2011; Paluch et al. 2013). Even after initial inoculation, follow up studies have found no trace of the inoculant species (Tata et al. 2010). This may be because native mycorrhizal species are better adapted to site conditions and outcompete packaged inoculants (Montes-Borrego et al. 2014; Teste et al. 2004).

Figure 5. A commercial mycorrhizal inoculant.

Action List for Enhancing Mycorrhizal Fungi in Landscapes and Gardens

Soil Management

Avoid unnecessary soil disruption

Rototilling and double-digging destroy hyphal networks. Compaction decreases pore space and reduces oxygen availability; excessive irrigation will also reduce soil oxygen levels.

Apply compost as a topdressing

Apply compost as a topdressing instead of working it into the soil (and disrupting the hyphal network). Organic matter will find its way into the soil naturally by water movement and soil fauna activity.

Use woody mulches

Use woody mulches (Cook et al. 2011) such as arborist wood chips, which are good reservoirs for fungal spores (Figure 6).

Figure 6. Arborist wood chip mulch.

Chemical Usage

Avoid using bactericides and fungicides

Bactericides kill beneficial bacteria that can assist in mycorrhizal activity (Hameeda et al. 2007; Vivas et al. 2003). Fungicides, whether organic or conventional, can kill nontarget fungi including mycorrhizal species (Ipsilantis et al. 2012). Use them only as a last resort for treating fungal disease; inoculation may be necessary afterwards to replace mycorrhizal species.

Apply fertilizer only when soil tests indicate a nutrient deficiency

Excessive nutrient levels (especially phosphate), whether from conventional or organic sources, inhibit root colonization by mycorrhizal fungi.

Plant Selection and Management

Use a handful of soil from your established landscape

Use a handful of soil from your established landscape if you want to inoculate container plantings or other isolated areas. Indigenous mycorrhizal species are plentiful, effective, and adapted to your soil conditions.

Include some low-growing, drought-tolerant groundcovers

These "living mulches" can facilitate mycorrhizal networks between plants (Cavender et al. 2003; Deguchi et al. 2007).

Use a variety of trees, shrubs, groundcovers, herbaceous perennials, bulbs, and annuals

Diverse landscape plantings favor mycorrhizal diversity (Hijri et al. 2006), especially woody species (Sorensen et al. 2003; Figure 7).

Figure 7. A diverse landscape will house diverse beneficial microbes including mycorrhizal fungi.

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Further Reading

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