Mycorrhizae in Production Agriculture

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Background

- Born and raised in Minot, ND
- Reside in West Fargo, ND
- Family
  - Melissa, Josie, Bode, and Gunnar

Background

- Graduated from North Dakota State University in 2002.
  - B.S. Crop and Weed Science

Background

- Worked in ag retail after college for 10 years as a salesman/agronomist
  - Hunter Grain Company 3 years
  - Maple River Grain & Agronomy 7 years
- Worked for Novozymes BioAg & Monsanto BioAg for 2 years
- Presently work for Crop Production Services as a wholesale distributor sales representative

Crop Production Services

Introduction

Objectives

- Introduce reader to mycorrhizal fungi.
- Show importance of mycorrhizal fungi to agriculture.
- Demonstrate benefits of symbiosis with plants.
- Introduce glomalin and the importance of mycorrhizal fungi to building soil structure.
- Leave reader with a better overall understanding of mycorrhizae and their role in improving agricultural productivity.

Introduction

- Arbuscular mycorrhizal fungi (AM fungi) are organisms that form symbiotic relationships with 70-90% of all plants (Maillet et al., 2011).
- They are **obligate biotrophs**, meaning they must form a symbiotic association with a host plant in order to complete their life cycle. These plants exchange C for increased nutrient uptake from the fungi for a symbiotic interaction (Gerlach et al., 2015).

Introduction

- Mycorrhizal fungi are ubiquitous in soils and make up between 5-36% of the total biomass of the soil and between 9-55% of the biomass of microorganisms in the soil (Goltapeh et al., 2008).
- The term mycorrhizae is derived from the Greek *mycos*, meaning fungus, and *rhiza*, meaning root. In Greek, *mycorrhizae* means fungus root (Parniske, 2008).

Corn, a crop that relies heavily on AM fungi. (Photo by Greg Mostad.)

Introduction

History and Taxonomy

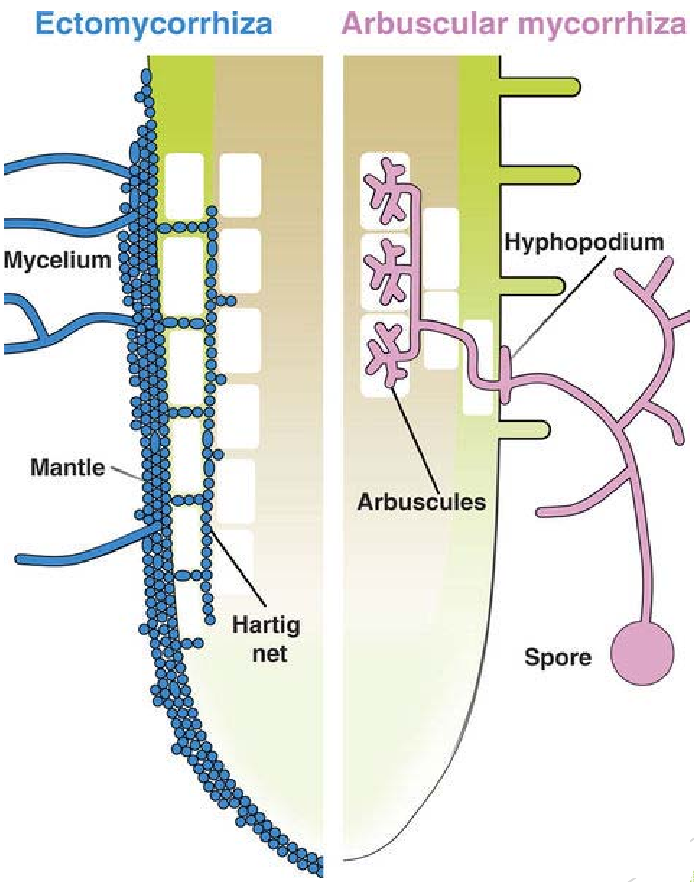
- All arbuscular mycorrhizae are part of the monophyletic phylum Glomeromycota, and most part of the order Glomerales.
- Mycorrhizal fungi are ancient living organisms. There is evidence of their existence for over 460 million years. Over that span of time, they have remained morphologically the same (Parniske, 2008).

Types of Mycorrhizal Fungi

Endomycorrhizal fungi – Part of the fungal hyphae is inside the plant cell, this group contains three types of mycorrhiza fungi.

- **Arbuscular Mycorrhizae** (AM fungi) - the most common type of mycorrhizal fungi, associated with 70-90% of all plants
- **Orchid Mycorrhizae**
- **Ericoid Mycorrhizae**

Ectomycorrhizal fungi – Fungus remains on the outside of plant cells (Parniske, 2008).



This figure shows ectomycorrhiza (left) and endomycorrhiza (right). (Figure from kenyon.edu.)

Mean percentage distribution of AM fungal species (Troeh and Loynachan, 2009).

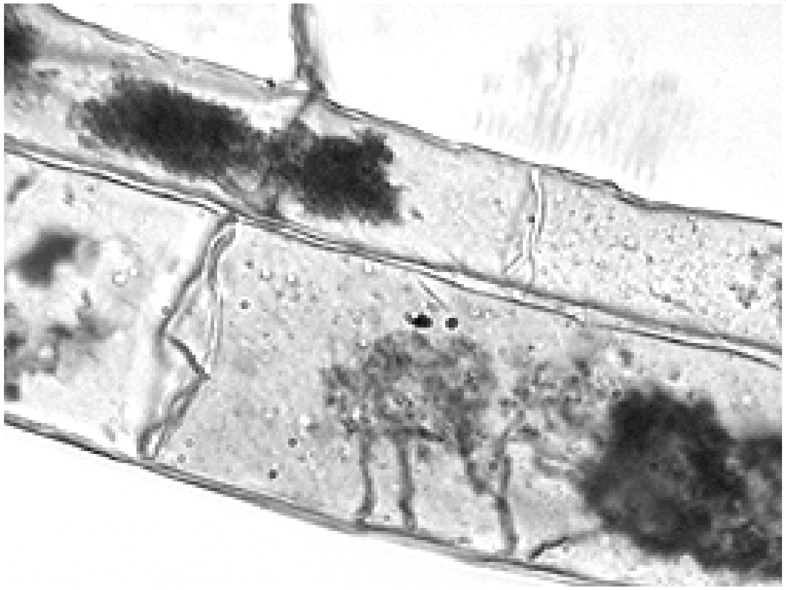
	Field Soil †		Trap Culture†,‡	
	Clarion	**Webster**	**Clarion**	**Webster**
Glomus claroideum	10	15	34	22
Glomus clarum	-	-	7	5
Glomus constrictum	-	-	<1	2
Glomus etunicatum	1	12	26	12
Glomus geosporum	0	1	<1	<1
Glomus intradices	9	1	1	2
Glomus mosseae	3	19	1	25
Glomus viscosum	45	23	6	10
Acaulospora spp.	1	14	2	2
Entrophospora spp.	-	7	<1	0
Gigaspora spp.	<1	<1	<1	<1
Paraglomus occultum	-	-	21	19
Other AM fungal spp.	31	18	2	2
Total Spores g^{-1}	0.29	0.44	21	19

†Values are averaged over 80 samples.

‡Greenhouse experiments conducted to produce healthy spores, evaluate cultivar compatibilities, and to stimulate sporulation of more AM fungal strains.

Types of Mycorrhizal Fungi

- As shown in the table from Troeh and Loynachan (2009), in our cultivated rowcrops in the Midwest, *Glomus* species tend to dominate.
- One of the main reasons why *Glomus* species may dominate over other genera of AM fungi may be their ability to propagate from both spores and broken pieces of hyphae (Troeh and Loynachan, 2009; Berruti et al., 2014).



AM fungi in corn root cells magnified 500x. (Photo by Kristine Nichols, USDA-ARS.)

Arbuscular Mycorrhizae Morphology and Life Cycle

- Examples of crops that **do not** form associations with mycorrhizal fungi are listed below.
  - Sugar beets
  - Canola
  - Mustard
  - Cabbage
  - Buckwheat
  - Cauliflower
  - Brussels
  - Broccoli

Canola also is a member of the Brassicaceae family and is a non-mycorrhizal crop. (Photo from North Dakota State University.)

Arbuscular Mycorrhizae Morphology and Life Cycle

- Examples of crops that **do** form associations with mycorrhizal fungi are these.
  - Corn
  - Soybeans
  - Wheat
  - Alfalfa
  - Sorghum
  - Rice
  - Cotton

Spring wheat is a mycorrhizal crop. (Photo from North Dakota State University.)

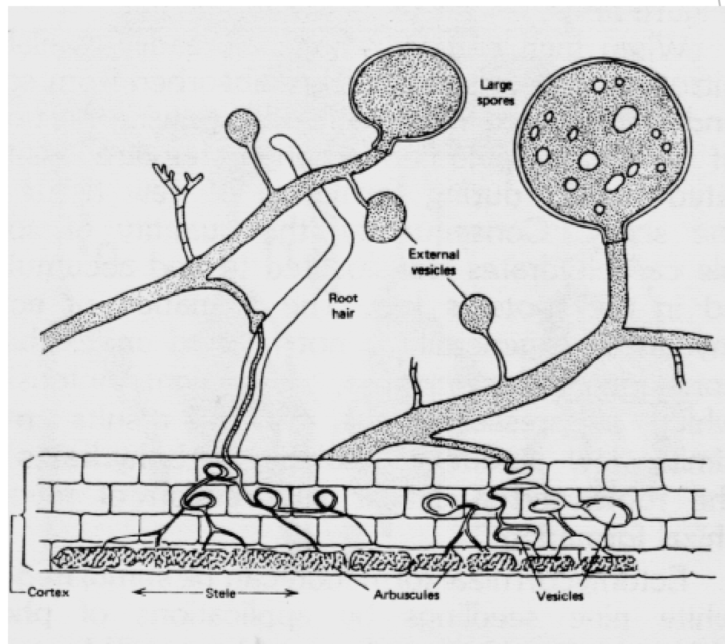
Fallow Syndrome

- In some cases, crops following a long-term fallow or following a non-mycorrhizal crop can exhibit P deficiencies. The P deficiencies are due to a reduction of AM fungal propagules (Troeh and Loynachan, 2003). AM fungi can propagate from spores and in some cases from broken pieces of hyphae.
- In addition, fallow periods or non-mycorrhizal crops can reduce glomalin levels in the soil, by reducing AM fungal populations that produce the glomalin (Wright and Nichols, 2002; Rillig and Mummey, 2006).

P deficiency in corn can be caused by fallow or non-mycorrhizal previous crop. (Photo from North Dakota State University.)

Arbuscular Mycorrhizae Morphology

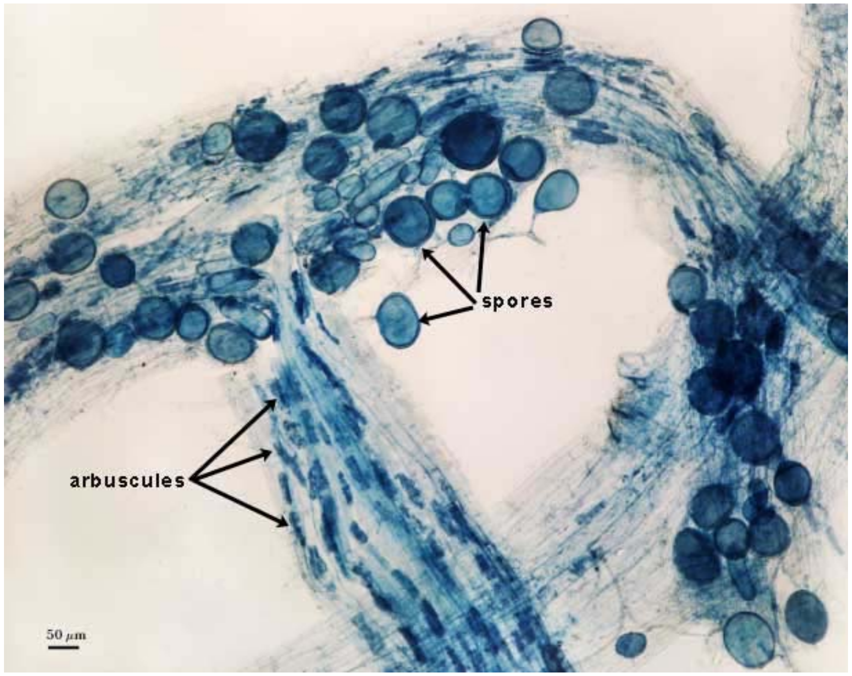
- **Arbuscules** – AM fungi form a shrub-shaped structure inside the root cortical cells by branching in several very thin hyphae. This is where the exchange of nutrients and C happens between the host plant and the fungus (Berruti et al., 2014).
- **Hyphae** – root-like structures that grow outside the root, in long distances to explore the soil for nutrients.
- AM fungi form hyphal networks that can contain over 100 meters of hyphae per cubic centimeter of soil, and are important for nutrient uptake and soil aggregation (Parniske, 2008).



This figure shows the morphology of endomycorrhizae morphology. (Figure from Purdue.)

Arbuscular Mycorrhizae Morphology

- **Spores** – Most AM fungi will propagate from spores in the soil. Some genera, like members of the *Glomus* genus, can also propagate from broken hyphae segments (Troeh and Loynachan, 2009).

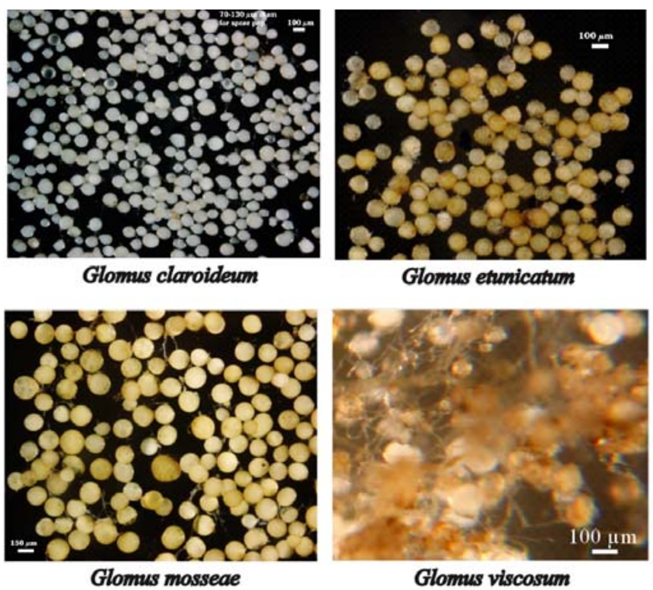


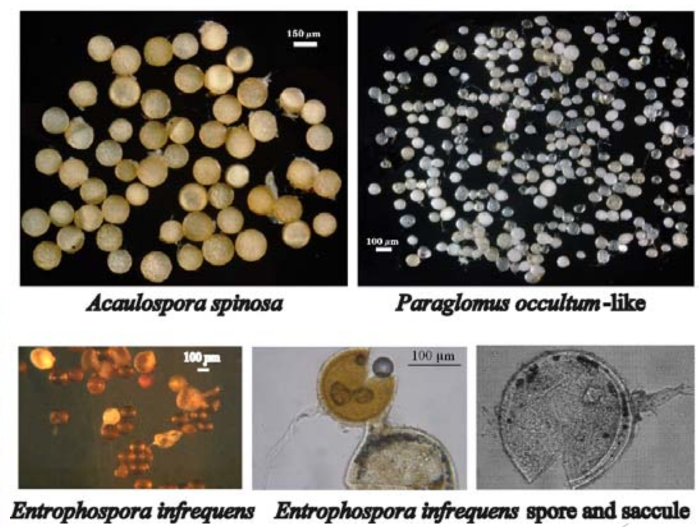
Glomus **spp. arbuscules and spores, International Culture Collection of Vesicular Arbuscular Mycorrhizal Fungi. (Photo from West Virginia University.)**

Arbuscular Mycorrhizae Morphology

Phylogeny of AM fungi

- Traditionally, AM fungi have been characterized using phenotypic characteristics (mainly spore morphology). Recently, molecular DNA sequencing analysis has been progressing and showing much more diversity within the Glomeromycota phylum (Berruti et al., 2014).





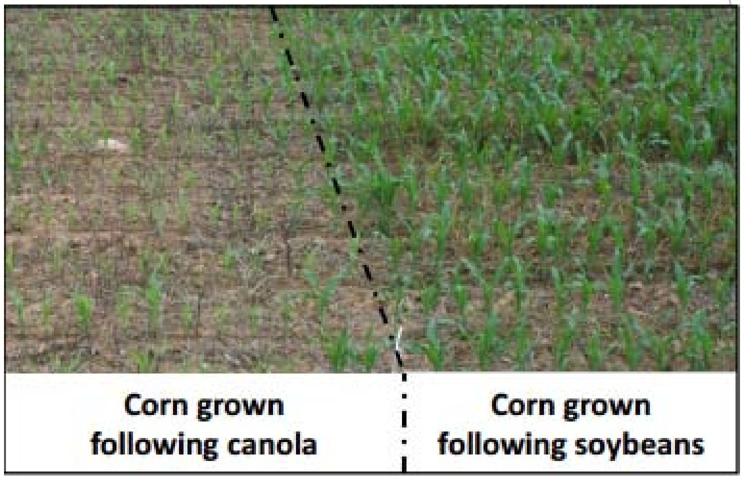
Examples of spore morphology of different species of AM fungi. (Photos from Troeh and Loynachan, 2009.)

Symbiosis with Plants

- Up to **20%** of a plant's fixed C is transferred to the mycorrhizal fungus in exchange for water and nutrients such as N and P (Hodge and Storer, 2015).
- Phosphorus is the most well known and studied nutrient linked to AM fungi. Since P is immobile in the soil, plants can greatly benefit from the hyphal network of the fungi to aid in P uptake.
- Research is showing that AM fungi are also very important in N uptake for the plant. The uptake of inorganic and organic forms of N by the fungi continue to benefit the host plant (Hodge and Storer, 2015).

Symbiosis with Plants

- AM fungal populations can be affected by crop rotation, tillage, or other management systems. Corn is a crop that is susceptible to early season P deficiencies and thus relies on help from mycorrhizal fungi to aid in P absorption (Sheng et al., 2012).
- Here is a picture of corn following a non-mycorrhizal crop (canola) vs. following a mycorrhizal crop (soybean). AM fungal populations are decreased due to the non-mycorrhizal crop, affecting the P uptake in the corn.



The previous crop (mycorrhizal vs. non-mycorrhizal) affects on corn growth. (Photo by Roger Koide and Kristin Haider, Penn State University.)

Nutrient Uptake and Transport

- Hyphal networks are very efficient at exploring the soil and bringing in phosphate, Zn, and ammonium (Gerlach et al., 2015).
- Plants benefit the most by increased **phosphate uptake**, due to solution available P being very immobile.
- In the soil there are three pools of P: fixed P, active P, and solution P. As solution P is removed, it is replaced by P from the less available active pool. Soluble P may only move up to 1 inch or less during a growing season (Busman et al., 2002).
- Hyphal networks can help extend the plant's availability to bring in more P from the solution P pool in the soil (Gerlach et al., 2015). They are also able to explore small pores in the soil not accessible by plant roots (Jakobsen et al., 2005).

Nutrient Uptake and Transport

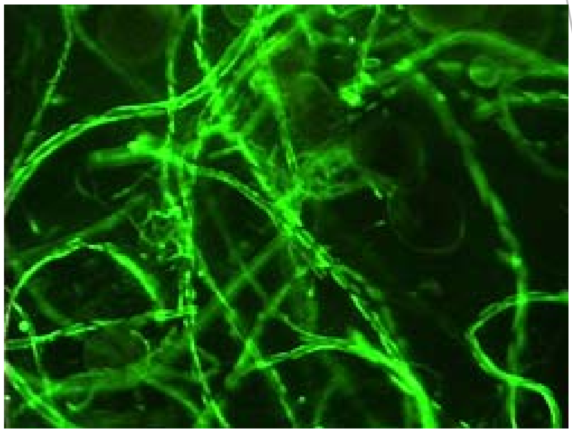
Nutrients taken in by plants that are infected and by those that are not infected with AM fungi when no P is added to corn.

Element	No Mycorrhizae	With Mycorrhizae
	----------------Micrograms/plant---------	
Phosphorus	750	1,340
Potassium	6,000	9,700
Calcium	1,200	1,600
Magnesium	430	630
Zinc	28	95
Copper	7	14
Manganese	72	101
Iron	80	147

(Dejong-Hughes, 2009.)

Glomalin Production and Role in Soil Aggregation

- As shown earlier, hyphal networks can contain over 100 meters of hyphae in 1 cubic centimeter of soil.
- AM fungi excrete a large amount of the glycoprotein glomalin and glomalin-related proteins. In fact, they are the only fungi that produce significant amounts of glomalin.
- **Glomalin** is a stable compound, insoluble in water, and resistant to degradation by heat. It is glue-like, that makes it great at aggregating soil particles (Rillig and Mummey, 2006).



Glomalin on mycorrhizal hyphae. (Photo by Kristine Nichols, USDA-ARS.)

Glomalin Production and Role in Soil Aggregation

- Between the massive amount of hyphae holding soil together and the glomalin they excrete, AM fungi are large contributors to **soil aggregation** and **C sequestration** (Leifheit et al., 2014).
- Glomalin concentrations have been shown to positively affect soil aggregate water stability across many soil types, different cropping systems, and management systems. Therefore, the production of glomalin plays an important role in soil aeration, plant nutrient uptake, drainage, and crop productivity (Singh et al., 2013).

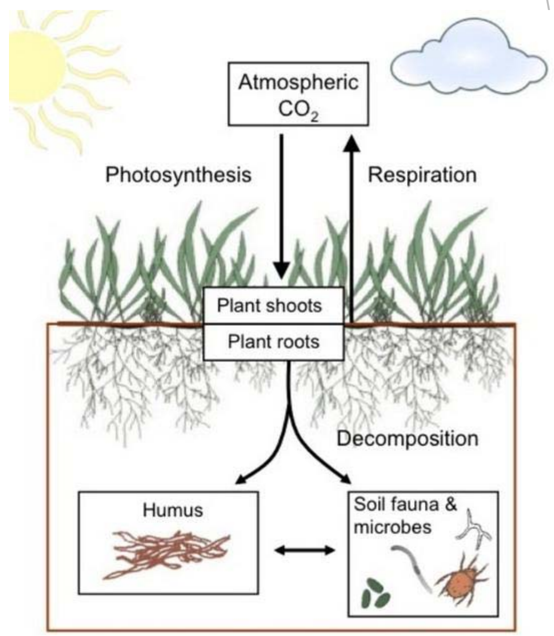
Glomalin extracted and dried. (Photo by Keith Weller, USDA-ARS.)

Glomalin Production and Role in Soil Aggregation

- Glomalin is estimated to last between 7 and 42 years in the soil. It has also been shown to account for up to 27% of the C in the soil.
- Wright found in a 4-year study at the Henry A Wallace Beltsville (Maryland) Agricultural Research Center that glomalin levels rose each year after no-till was started. In her field study, glomalin levels were 1.3 milligrams per gram (mg/g) of soil in year one and after three years of no-till, they were 1.7 mg/g. In an adjacent field that was plowed each year, the glomalin levels were 0.7 mg/g and in a nearby 15-year grass buffer strip the glomalin level was 2.7 mg/g.
- Management practices and crop rotations both have an impact on the AM fungal populations in the soil and the amount of glomalin available that helps aggregate the soil and give the soil its tilth (Wright and Nichols, 2002).

Nutrient Cycling

- AM fungi are very important in C cycling. Plants contribute 5-20% of their photosynthetically fixed C to the fungi. This makes them very significant in contributing to the global C cycle.
- AM fungi were originally thought to contribute mainly to P acquisition in plants, but they have also been found to transfer other nutrients, especially N. In some cases, large amounts of N are transferred to their host plants.
- Since N and C cycling are closely linked, and we know that AM fungi have a large impact on C cycling, they also have a large impact on N cycling (Hodge and Storer, 2015).



Soil C Storage. (Figure from Science Education Research Center, Carleton College.)

Effect of Management on Mycorrhizal Populations

- Management practices that we use in agriculture can affect populations and species make-up of mycorrhizal fungi (Sheng et al., 2012). Changes in agricultural practices can influence changes on the soil and therefore can have an influence on soil microorganisms, such as mycorrhizal fungi (Berruti et al., 2014).
- These are some management practices that can affect mycorrhizal fungal populations and colonization of roots.
  - **Fertilization**
  - **Tillage**
  - **Crop rotation**

Effect of Management on Mycorrhizal Populations

Fertilization

Repeated P applications to the soil can inhibit AM fungal development (Sheng et al., 2012).

As nutrients become more readily available in the soil, plants tend to rely less on AM fungi. As their dependency decreases, the richness and diversity of the AM fungal community also decreases.

Some AM fungi taxa have been found to be more sensitive to fertilization than others, resulting in species shifts under different crop management practices (Berruti et al., 2014).

Spreading fertilizer, P fertilization can inhibit AM fungal development. (Photo by Greg Mostad.)

Effect of Management on Mycorrhizal Populations

Tillage

Tillage of soils destroys the extraradical mycelial network that was formed by AM fungi. Tillage can also cause species shifts within the soil. An example is the large amount of Glomeraceae species found in tilled soil all around the world due to their ability to propagate from hyphal pieces (Berruti et al., 2014).

Tillage prior to corn planting can destroy extraradical mycelial networks. (Photo by Greg Mostad.)

Effect of Management on Mycorrhizal Populations

Crop Rotation

Monocultures can be very harmful to AM fungal populations and diversity. This can be especially true when crops are not highly dependent on the mycorrhizal symbiosis (e.g. wheat), or crops that are non-mycorrhizal hosts (e.g. canola) are grown in succession. Less diversity in crop rotation can affect the AM fungal community to be both less diverse and less parasitic, meaning they are less aggressive at colonizing the host plant. The impact of crop rotation is crucial to the diversity and population of AM fungi (Berruti et al., 2014).

Corn crop in corn and soybean rotation. (Photo by Greg Mostad.)

Mycorrhizal Inoculants

- Currently there are commercially available mycorrhizal inoculants on the market. Generally they are expensive and have not become popularized in the row crop market. Some of this is due to the cost of producing an organism that is an obligate biotroph and requires a host to complete its life cycle.
- AM fungal inoculants have not been adopted in many areas, probably due to quality and effectiveness of the marketed products (Jakobsen et al., 2005).
- Efficacy of AM fungal inoculants remains largely dependent on local environmental factors. These can include the following.
  - Soil mineral content
  - Interaction with cultivated crop
  - Competition with local indigenous strains
- Research continues as companies look to find mycorrhizal inoculants. As research has shown, good colonization of crop roots does not directly translate into increased crop yields (Faye et al., 2013).

Summary

- Arbuscular mycorrhizal fungi are very important in agriculture. They are extremely important in helping plants mine the soil for nutrients and water by increasing the volume of soil that can be explored through their hyphal networks.
- These fungi are also instrumental in building soil structure. The glycoprotein glomalin that they produce helps aggregate soil particles to build structure and the shear amount of hyphal network they produce helps hold those aggregates together.
- AM fungi are also very important for nutrient cycling. They account for a large percentage of the total organic portion of the soil as well as helping uptake of N, P, and other nutrients. The exchange of plant-fixed C for soil nutrients helps convert atmospheric C into soil organic matter over time.
- Arbuscular mycorrhizal fungi are an extremely important part of our agricultural system. They are organisms that do not get a lot of press, but nonetheless, they are very instrumental in the success of our cropping systems.

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Questions