Mycorrhizae

"Fungus Root"

As the very definition of the word "mycorrhizae" implies, these important soil organisms act as an extension of the root system.

Mycorrhiza play very important functions in agricultural production:

1. Phosphate uptake – The most studied of all topics about mycorrhizae relationships with plants. The effectiveness of these fungi to increase the uptake of soil P is due to the action of extending the root system. Soil phosphates are very immobile; therefore, these fungi increase the area of root to soil contact. Mycorrhizae can increase the effectiveness of applied phosphates by up to 300%.
2. Mineral uptake – Due to the method by which mycorrhizae can solublize soil P, the availability of minerals such as K, Ca, Mg, Zn, Cu, Mn & Fe can also be increased in the presence of these organisms on root hairs of plants.
3. Protect roots – Mycorrhizae are very important for increasing the ability of plants to grow in high salt levels. There is also evidence that these fungi can protect plants from certain soilborne diseases by producing "antibiotics", altering the root epidermis cells and competing with disease organisms for the food & sites available for attack.
4. Drought resistance – A critical role of mycorrhizae in arid areas is the effectiveness of the mycorrhizae to get water from crevices in the soil and soil colloids that the physical plant root hair cannot.

It is important to understand that there are different types of mycorrhizae that agriculturally important plants utilize. This understanding can also lead to a better practical utilization of these important organisms.

Two Main Types of Mycorrhizae

There are two important types of mycorrhizae:

1. "Ecto" – mycorrhizae.
2. "Endo" – mycorrhizae.

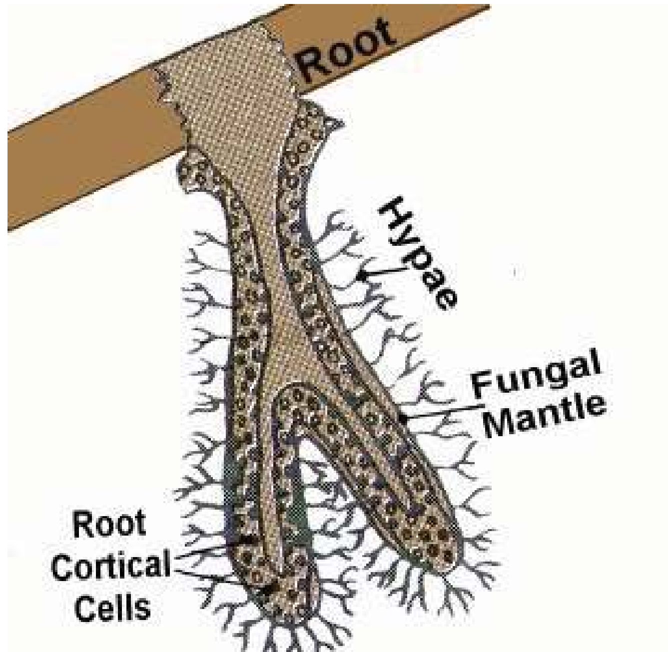
Taking a closer look at how these two major groups of mycorrhizae function yields important information for the agricultural significance and our potential ability to regulate these organisms in such a way to benefit profitability of growers.

Ectomycorrhizae

These groups of fungi are mainly found growing with the roots of trees such as pine, birch, hemlock, beech, oak, spruce and fir. Therefore, they are a practical importance to tree and ornamental producers, but of limited importance in most agricultural crops.

The fungi are facultative organisms, which means that they can get nutrition from many different sources. They can live independently in the soil. The practical side of this is that they can be easily cultured on artificial media and inoculated to soils. This is very important for tree nurseries in that some trees cannot properly function without the presence of these fungi.

The most important difference to note is that this type of mycorrhizae grows in between the root cells, not into them.

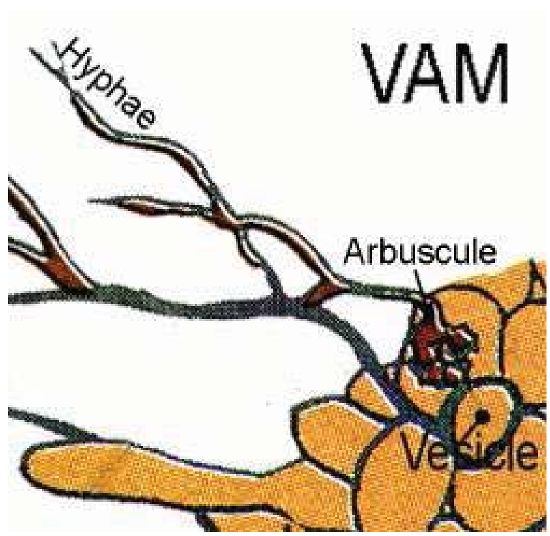


"The Nature & Properties of Soils", pg 349

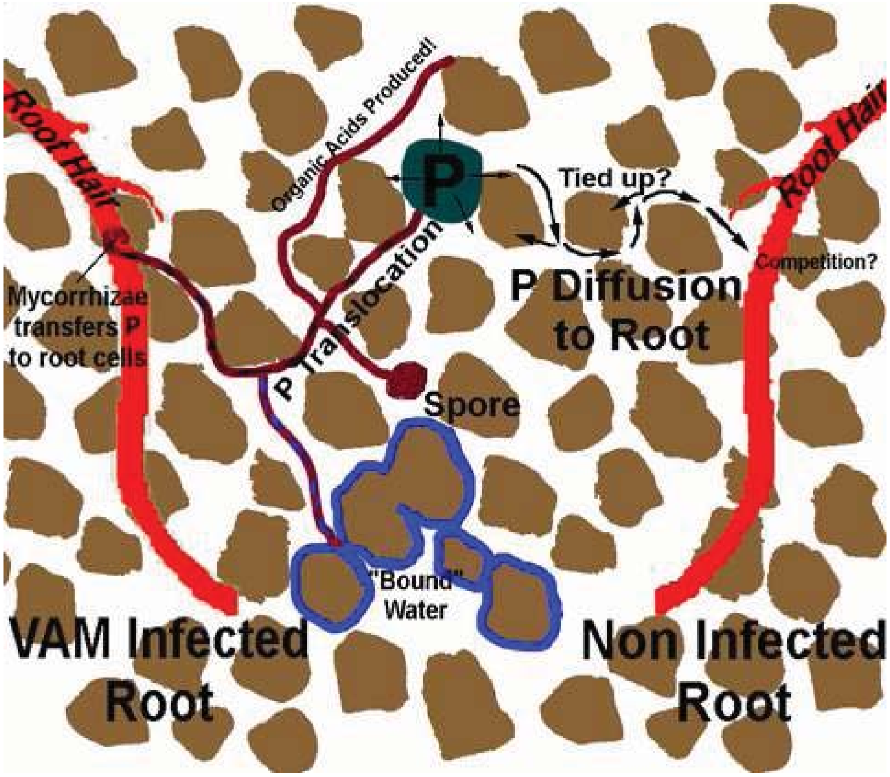
Endomycorrhizae

The most studied and agriculturally important group of endomycorrhiza is called Vesicular Arbuscular Mycorrhizae (VAM). The fungal hyphae actually penetrate the cells of the root hairs and once inside the plant form highly branched structures known as *arbuscules*. These structures transfer the mineral nutrients from the fungi to plants and in return feed the outer hyphae with sugars from the photosynthesis mechanism of plants.

The *vesicle* serves as an important storage organ for these mycorrhizae.



The effectiveness of mycorrhiza comes from the fact that it can grow faster and through much smaller soil spaces than the physical root hair itself. As a matter of fact, VAM can extend itself from 2" to 6" from the physical root hair.



Mycorrhiza are capable of increasing the uptake of more than just phosphorus. This is a result of the increased root to soil contact of properly established fungi. The data in the table below taken from Lambert, Baker & Cole in Soil Sci. Soc. Amer. J, v43:976-980.

"The Role of Mycorrhizae in the Interactions of Phosphorus with Zinc, Copper and other Elements"

(expressed in micrograms per plant)

	No phosphorus added		25 lbs./acre phosphorus added	
Element in Plant	No Mycorrhiza	Mycorrhiza	No Mycorrhiza	Mycorrhiza
P	750	1,340	2,970	5,910
K	6,000	9,700	17,500	19,900
Ca	1,200	1,600	2,700	3,500
Mg	430	630	990	1,750
Zn	28	95	48	169
Cu	7	14	12	30
Mn	72	101	159	238
Fe	80	147	161	277

These beneficial organisms are the most overlooked valuable resources in agriculture today. **Properly infected roots have the ability to increase the plants surface area contact to the soil by up to 10 times!** This is especially important for nutrients with low soil mobility, such as phosphorus. The valuable resource is often unknowingly suppressed, as with fumigation, as illustrated in the table below. The table illustrates the effect of fumigation on growth of plants. As one can see, carrots are more affected than wheat; therefore, wheat has less of a dependence on VAM, but also can support VAM under more adverse conditions.

A look at mycorrhizae in the aspect of plant growth (in dry W in g per test)		
Crop	*Fumigation*	*Non-fumigation*
Carrot	0.4	8.5
Leek	0.4	4.4
Tomato	2.5	4.1
Wheat	1.7	2.0

The natural dependence of plants on mycorrhiza is an important consideration in employing methods for mycorrhiza support in practical agricultural situations. As illustrated below, many agricultural crops rely in different degrees on the association of these beneficial organisms on their roots.

Mycorrhiza Dependency	Potential yield loss Without mycorrhiza	Crop:
Very High	Greater than 90%	Linseed, Flax
High	60% to 80%	Sunflower, peas, other legumes
Medium	40% to 60%	Wheat, barley, oats, and most vegetables & fruits.
Very Low	0% to 10%	Canary, native grasses
Nil	0%	Canola, cabbage, broccoli, sugar beet

Some crops, such as sunflowers, are very dependent on the association of mycorrhiza with the root, however, do not underestimate the effect of these fungi on crops such as wheat or barley. Under "perfect" conditions such as good soils and weather patterns, these fungi may not show an economical return, but as stresses (nutrient deficiencies, imbalances & water stress) increase, so does the positive effect of mycorrhiza.

How Plants "Choose" Mycorrhiza

The beneficial effects of mycorrhiza are easy to identify. However, how does one effectively begin to establish and use this system of plant fertility enhancement? Is it possible to use cultural practices, nutrients or inoculations to help mycorrhiza "infect" plant roots?

In commercial agriculture, the most beneficial of this mycorrhiza are the VAM (vesicular arbuscular mycorrhiza) or AM (arbuscular mycorrhiza), which are endomycorrhiza. Unlike the ectomycorrhiza, found mostly in forest systems, these agricultural types cannot be grown in pure culture to be inoculated to fields.

In an overall evaluation, it must be considered that beneficial infections of VAM or AM on the roots of plants is much like the infection of a non-beneficial infection of a plant root disease. Cool, wet and anaerobic (low oxygen) in soils tend to support the development of non-beneficial types of root fungi. As a whole, however, most types of root/fungi relationships are beneficial.

On a global basis, it is reported that mycorrhiza occurs in 83% of dicots and 79% of monocots. General conditions that negatively effect the beneficial infection of mycorrhiza are salinity, waterlogged soils and extremely high or low soil fertility.

The method of establishment and growth of these beneficial organisms must be based on an understanding and management of the conditions in which they can naturally develop in soils and on the roots of plants.

First one must understand that the establishment of beneficial mycorrhiza is a result of many different conditions, some which are controllable and some uncontrollable. Some of these factors are:

1) A preexisting network of microbiology in the soil enhances infection. The source of VAM can be initiated from existing spores or root residues.
2) Fungi are often visible in a highly organized branching network, which is destroyed by cultivation. This is an advantage of no-till agriculture, where practical.
3) Root exudes are extremely important for triggering the growth of VAM or AM with roots.
4) VAM and AM are enhanced by elevated CO_2 contents near the root hair due to bacteria in the rhizosphere.
5) As plant breeders make plants more resistant against root infections of disease, there are suspicions that this also effects VAM infection.
6) Low or high rates of phosphates and nitrogen can also severely suppress VAM infection, therefore, a balanced nutritional approach is important.

By looking at each of these points in more detail, we hope that valuable information to develop programs of fertility, inoculation and management can be developed to produce predictable field results.

The Source of Spores

Although fumigation severely disrupts microbial growth in the soil, microbes in general are very resilient and have the ability to survive under very detrimental conditions. When the right conditions are created, the microbes will come out of their dormant state and again reproduce. The same applies to disease causing organisms, therefore, no matter how much fumigation is used; disease comes back if the conditions are created for it. To make a general statement from this in regards to the source of spores for VAM or AM establishment, it is proper to say that it is not a matter of supplying the spores in a product, but supplying the conditions for the existing spores to develop.

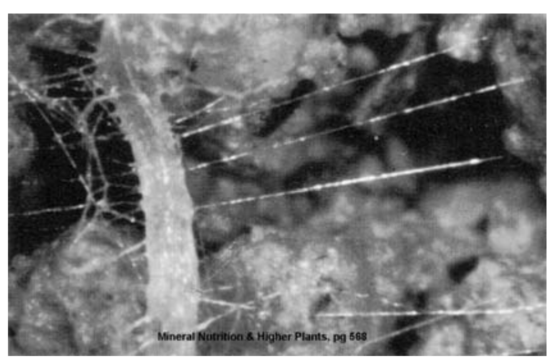
Another source of VAM or AM inoculation is from neighboring plants. This is an often-overlooked factor in permanent crops such as vineyards and orchards. As TNS is developed, we have to look closer at the concept of fertilizing and farming the area in between the rows to feed the vines or trees. The right types of cover crops will support disease protecting and nutritional uptake enhancement of the roots of the vines or trees.

In row crop agriculture, an overlooked source of spores and foodstuffs for the supporting microbes of VAM and AM is the rotation of green manure crops such as legumes. Considering that growers spend more and more on chemistry to protect disease prone crops, the cost of using a preplant green manure crop is once again becoming a feasible alternative. What is the cost of a green manure crop that could eliminate the need for fumigation, increase plant fertility and enhance the ability of plants to protect themselves from plant diseases and insects?

Tillage

Tillage requirements are often needed to aerate soils, prevent weed growth and of course to prepare soils for proper crop establishment. The concept of eliminating tillage in most cases is impossible. However, as our understanding of soil microbiology increases, in certain conditions such as recrop wheat, no-till or minimum tillage is a viable alternative and very supportive of VAM and AM establishment.

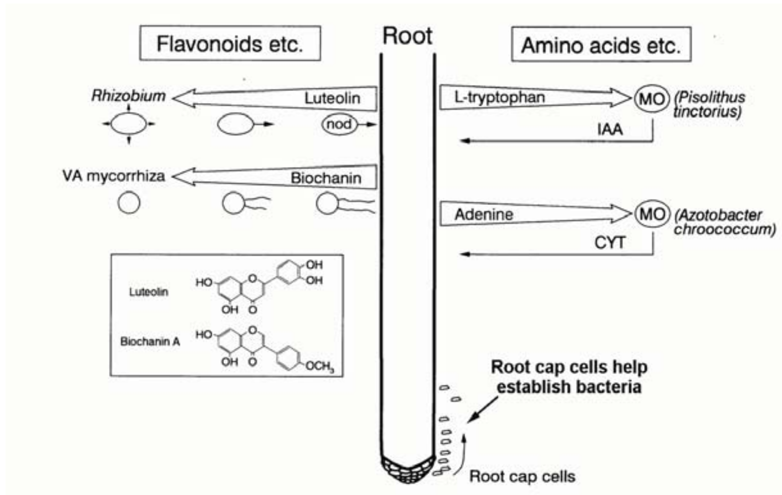
In most agricultural situations it is important to consider the negative effect of tillage on VAM or AM establishment and develop programs to reestablish the organisms after tillage and/or eliminate needless tillage practices. This is especially important in practices where tillage and possible root pruning (destruction of fungal network) can occur. To give an illustration of the delicate nature of VAM, to the right is a picture of VAM on potato roots.



Root Exudes

Plants manufacture and excrete many compounds that are essential for plant nutrition and function. A small, but important, group of compounds that plants can manufacture are exudates that act as "signals" to regulate microbial development in the rhizosphere. These compounds are essential in direct and indirect support of beneficial establishment and development of mycorrhiza.

Legumes produce *luteolin*, a signal for *rhizobium* at concentrations as low as 1 ppb. Other flavonoids from legumes can act as suppressors for pathogenic fungi.



Roots produce compounds such as *biochanin,* which helps trigger the development of VAM.

More importantly for the establishment of VAM on plant roots is the effect of other parts of the microbial community. Root cap cells act as an important source of food and energy for the development of a strong population of bacteria near roots. The decomposition of this organic matter periodically produces elevated levels of carbon dioxide (CO_2) near the root, which is by far the most important stimulator of VAM development.

These rhizosphere bacteria are also important for the suppression of certain soil borne root pathogens that can latter be competition for beneficial strains of VAM or AM.

As further described in a paper dedicated to root exudes and their effect on plant nutrition, these compounds are at the center of a TNS system. Well-planned and balanced fertilizer applications with the addition of microbial stimulants such as EHP - Amino Acids or 0-15-15 VAM are important components in establishing VAM or AM on the roots of plants.

Soil Air & Gases

One of the most predominate stimulators of mycorrhiza development with plant roots is periodic elevated levels of CO_2.

Soil aggregate structure and proper management of water to maintain an optimum soil gas to soil water ratio is critical for the establishment of VAM. Waterlogged soils and soils with no aggregate structures in the vicinity of the root hairs do not have the cycles of high CO_2 and O_2 levels required for the proper cycling of diverse microbial populations. In practical applied microbiology, it is not necessarily the level (or number) of microorganisms present, but the balance and effectiveness of the microorganisms to properly cycle organic compounds and produce the environment for the next level of growth.

In the establishment of VAM one such cycle can be illustrated. Considering that there is good soil structure that is well aerated. Aerobic bacteria will flourish and utilize the oxygen present, creating a higher level of carbon dioxide as well as residual chemicals. The elevated CO_2 will help trigger the VAM, which is protected by the residual chemicals that the bacteria produced to suppress other fungi. This is a simplified, but important point to understand.

Plant Types

Canola, cabbage and sugar beets do not require or are capable of supporting VAM. This can be due to root exudes, toxins or enhanced defense reactions against any type of infection of the root cells (bad or good).

There is evidence that as plants are breed to grow roots more capable of suppressing disease, that they also become harder to establish beneficial VAM on. This opens a window of opportunity for more intense fertilization practices in that some plants are quite dependent of VAM for nutrient uptake.

Nutrient Supply for VAM

Research indicates that VAM requires small amounts of phosphates to grow. Yet, there is also an optimum supply of phosphate, because as levels of phosphates get higher, VAM establishment begins to decrease.

This is also correlated with increasing rates of nitrogen, especially ammonium with high rates of available phosphate. It is thought that this is a result of lower root exudates produced by plants under high nutrient availability.

This correlation of low rate applications of a high-grade orthophosphate source has been demonstrated on potatoes in Idaho more 4 years. Five to ten units of P per acre were sufficient to get excellent yield and quality. Increasing amounts caused yield reduction. High rates of 10-34-0 also reduced yield.

An example of such a test is as follows:

A common practice in this part of Idaho is high rate applications of manure (30 tons per acre) and is planted into barley. The 2nd year potatoes are planted. The field received 300 lbs per acre of 16-20-0-12s after planting. The follow P and biological treatments were sprayed over the potato seed at planting.

	Raw Manure	Dry Fertilizer	Starter P	Biological	Yield
Bio-Gro	30 tons/acre (2nd year)	48N – 60P – 36S	15 lbs/acre 12-61-0	25 oz BG 2000	404 sacks
Huma-Gro	30 tons/acre (2nd year)	48N – 60P – 36S	12 gal/acre 10-34-0	32 oz Blend	362 sacks

Another test involved a side dress of a high P solution with and without a high-grade low P in row treatment.

Treatment	Control	High P + Starter	Starter Only
Fall applied	300 lbs 11-52-0	300 lbs 11-52-0	300 lbs 11-52-0
Spring Band	10 gals 10-34-0 10 gals Thiosul 5 gals 32-0-0	10 gals 10-34-0 10 gals Thiosul 5 gals 32-0-0	none
Spring Broadcast	200 lbs 21-0-0-24s 100 lbs 0-0-60	200 lbs 21-0-0-24s 100 lbs 0-0-60	200 lbs 21-0-0-24s 100 lbs 0-0-60
Air Applied	100 lbs 46-0-0 10 lbs Zinc sulfate	100 lbs 46-0-0 10 lbs Zinc sulfate	100 lbs 46-0-0 10 lbs Zinc sulfate
Water Run	21 N & 48 S (Thiosul)	21 N & 48 S (Thiosul)	21 N & 48 S (Thiosul)
Starter (in row)	None	4 lbs 12-61-0 12 oz BG 2000 25 oz BG 3000 3 oz Zinc	4 lbs 12-61-0 12 oz BG 2000 25 oz BG 3000 3 oz Zinc
Sacks per acre	**322**	**350**	**374**

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