# A Plant Evolution Revolution

## Mycorrhizal Fungi Expand Contemporary Cropping Opportunities

*by Mike Amaranthus, Ph.D. & Larry Simpson*

*A healthy mycorrhizal-inoculated organic winter wheat field in Canada.*

Soil biology has emerged over the last decade as a critical part of the knowledge base for successful and sustainable agricultural production. A key component of biology is the profound plant/mycorrhizal fungi relationship, which has enormous potential for improved management of contemporary farming systems. Although using these fungi has the potential to revolutionize agriculture they are certainly not new in terms of the evolution of plants.

### WHERE WE'VE BEEN

The fossil evidence indicates that the specialized "mycorrhiza" (meaning "fungus-root") plant relationship dates back over 460 million years and actually played a key role in allowing plants to utilize terrestrial habitats. Without mycorrhizal fungi, today's crop plants might not exist, unless you are farming seaweed! For the first 75 million years that plants colonized dry land, they did not have differentiated root tissue and depended entirely on this symbiotic relationship with mycorrhizal fungi to access nutrients and moisture from the various and often harsh terrestrial environments. The root structures of plants actually evolved specifically as specialized attachment sites to better accommodate these fungi and the efficiencies available through the symbiotic "trading" of water and nutrients for sugars produced by photosynthesis.

In this symbiosis, the plant is provided better access to and uptake of nutrients and water from the soil. In return, the fungus, which cannot synthesize its own nourishment, receives its energy source in the form of carbohydrates donated by the plant. This highly successful system continues in 90 percent of plant species today.

Agricultural science has only in the last decade begun to recognize the importance of mycorrhizal fungi in farming ecosystems. Since before World War II, scientific and technological advances in agronomy have focused primarily on the development of chemical and mechanical approaches to improving crop production yields. Nutrient needs have been addressed using synthetic fertilizers while weed suppression has been accomplished through tillage and herbicides and plant diseases controlled using an array of chemical pesticides. More recently, modern science has begun to understand that in natural habitat plant roots are a complex mixture of both fungi and plant that is fundamental to life on the planet. The vast majority of crops form an association with these specialized mycorrhizal soil fungi in order to maximize performance. Among the few but notable exceptions are members of the Brassicaceae plant family (cabbage, broccoli, cauliflower, radish, turnips, canola, etc.) the Amaranthaceae plant family (beets, spinach, chard, etc.) and the Polygonaceae plant family (rhubarb, buckwheat). Virtually all other crop plants worldwide are meant to host some form of mycorrhizal association.

### WHAT ARE MYCORRHIZAL FUNGI?

The body of the mycorrhizal fungus consists of microscopic filaments called *hyphae*. Individual hyphae are approximately 1/25th the diameter of a human hair and can grow up to 15 to 25 inches in length. These strands grow from within and around the root cells of the host plant, spreading out into the surrounding soil, greatly increasing the surface area of the root system. The most widespread type of mycorrhizal relationships are known as arbuscular mycorrhizae (also commonly referred to as "AM," "VAM" or "endo mycorrhizae"). As stated above, most agricultural plants, including most grains, vegetables, orchard trees, vines and turfgrasses evolved with, and are naturally "designed" to achieve optimum growth and vigor by forming these fungal relationships. There are approximately 150 arbuscular mycorrhizal (AM) fungal species on the whole planet forming with perhaps 300,000 plant species. Nearly all of the AM fungal species are generalists which will associate with a wide variety of plants, in a broad assortment of soil types, geologies, topographies and climates.

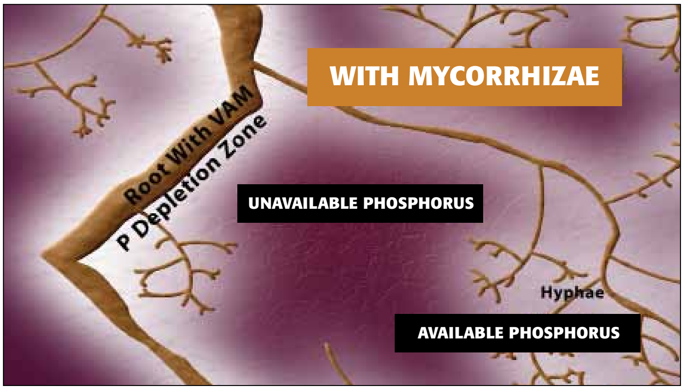
The numbers of hyphae on a root system can be prodigious. Just a teaspoon of healthy soil can contain up to several miles of fungal hyphae. The resulting nutrient and water uptake efficiency of crop plants is increased considerably. Agricultural soil often contains abundant "pools" of nutrients but the availability of these nutrients to the crops themselves may be limited.

### WHAT THEY DO

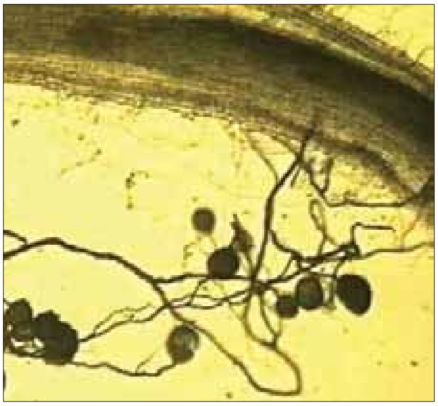
This plant-fungus association can deliver considerable benefits in agricultural operations. The effect on the root system of a mycorrhizal-colonized plant is extensive. As part of this relationship, most of the absorbing area of the root system is actually fungal hyphae. Hyphae are far thinner than roots or root hairs and are able to penetrate the tiniest pores and fissures in the soil.

Research confirms that mycorrhizae are particularly important in mobilizing phosphorus, nitrogen, zinc, iron, calcium, magnesium, manganese, sulfur and other important soil nutrients by enzymatic release from tightly held chemical bonds and transporting them back to the plant. Crop plant uptake and utilization of fertilizer inputs likewise becomes far more efficient, often leading to significant savings in fertilizer costs.

But mycorrhizal benefits do not stop there. These fungi also play a definitive role in a plant's natural defense against fungal root diseases such as *Pytophthora*, *Fusarium*, *Phythium* and *Rhizoctonia*. Mycorrhizal fungi produce and release suppressive exudates such as antibiotics that inhibit infection by these and other fungal root pathogens. Studies have documented that mycorrhizae also defend root systems by forming a physical barrier to deter invasion by soil pathogens.


*Drawing of AM fungal hyphae (left) without and (right) with mycorrhizal filament accessing pools of phosphorus in the soil.*



## Mycorrhizal Fungi

- Mycorrhizal fungi colonize the plant's root system and develop a symbiotic association called a "mycorrhiza."
- Form a network of filaments that associate with plant roots and draw nutrients and water from the soil that the root system would not be able to access otherwise.
- Mycorrhizae can form on more than 90 percent of crop species.
- Certain cropping practices reduce or eliminate mycorrhizal fungi.

*Arbuscular mycorrhizal (AM) fungal hyphae.*

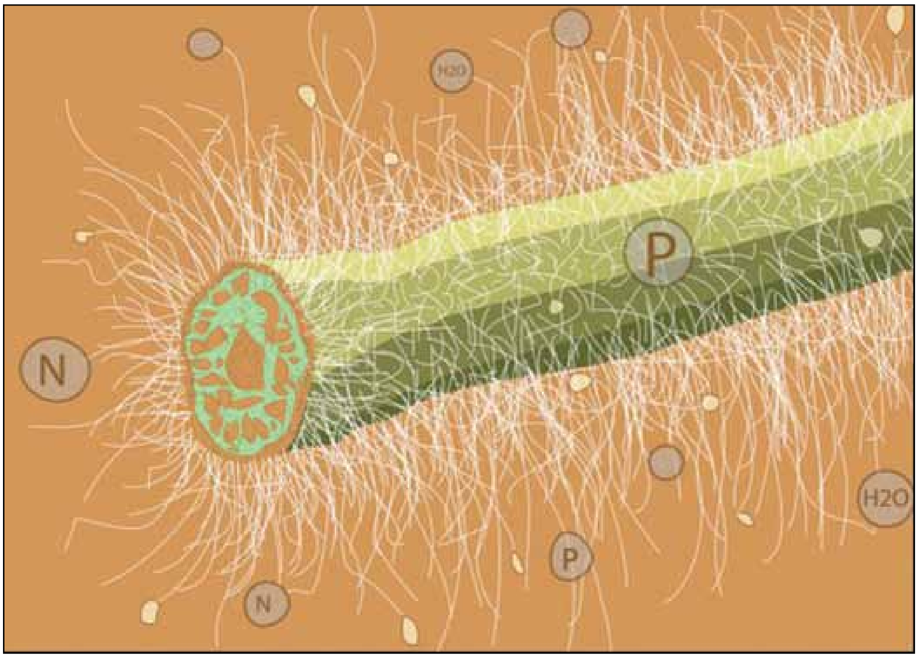



*Diagram of thin mycorrhizal filaments accessing nutrients.*

## Mycorrhizae Advantages

- Allows plants to draw more nutrients and water from the soil, including nitrogen and phosphorus
- Results in vigorous and healthy plants
- Better yields
- Protects roots
- Increases tolerance of drought and others stresses
- Enhances flowering and fruiting
- Reduces nutrient loss
- Reduces weed competition

*Drought stressed conventional, non-mycorrhizal corn wilt (right) compared to organically grown corn (left) at the Rodale Institute.*

This barrier is made of "chitin" (the same tough material that is in mammal claws and insect shells) which forms a tough, protective layer over the outside of root cells.

### DROUGHT TOLERANCE & YIELD

No one understands better than farmers that agriculture's need for fresh water is not always in sync with nature's inclination to provide it. We often see abundant, lush vegetation in natural and wild systems without the benefit of irrigation. How do natural areas provide for such luxuriant plant growth without irrigation?

One key factor is the mycorrhizal threads attached to plant roots, which so thoroughly scour the soil for available resources. They absorb water during periods of adequate soil moisture, then retain and slowly release it to the plant during periods of drought. Plant systems in natural areas generally achieve levels of drought tolerance far exceeding those found in agriculture partly due to the enormous web of mycorrhizal hyphae which act like a giant sponge to protect the plant communities from extreme soil moisture deficits.

Mycorrhizal filaments can penetrate into the smallest of soil pores and fissures to access microscopic sources of water that are unavailable to the thicker roots. An extensive body of research documents the importance of the mycorrhizal relationship for efficient water use and drought protection among a wide array of important crop species. The declining availability of water and its ever-increasing cost are formidable issues facing today's farmer and mycorrhizal fungi can be powerful tools to enhance water-use efficiencies.

Monitoring various crops indicates that mycorrhizal inoculation is having a positive effect on yields. For example, data presented at the 2010 National Allium Research Conference in Sparks, Nevada showed onion seed treated with a powdered endo-mycorrhizal (4-species) product outperformed controls. Average yields on the mycorrhizal-treated onions were 62 percent greater compared to controls and significantly greater than any other treatments. At this rate of increased production, the return to the grower (at $10 per 50 pound bag and an extra 600 bags acre) would be $6,000 per acre on a $20 per acre investment in mycorrhizal inoculum. Recent harvest results of a rice trial in side by side 75-acre blocks in California's Sacramento Valley yielded 8 percent more grain in the MycoApply inoculated seed area compared to the control area — an extra $173 per acre and a 10-fold return over the cost of the mycorrhizal inoculum. In another 2010 California study, Barley seed inoculated with a powdered, 4-species endo-mycorrhizal product resulted in average yields of 7,778 pounds per acre compared to 6,030 pounds per acre in control areas — a 29 percent increase. The mycorrhizal-inoculated barley was at least 6 inches taller than the untreated crop and netted an extra $145 per acre. In Wisconsin at Gagas Farms, Inc., soybeans were inoculated with a liquid mycorrhizal inoculant. Yield was significantly increased by over 9 percent compared to side-by-side, non-treated areas.

## CONSERVING NUTRIENT CAPITAL

Nutrient loss from agricultural ecosystems is among the top environmental threats to ecosystems worldwide, leading to reduced plant productivity on the farm and eutrophication of surface water near nutrient-rich ecosystems. Hence, it is of pivotal importance to understand AM fungi, whose absorbing filaments are widespread across nearly all natural ecosystems and reduce nutrient loss from irrigation or rain-induced leaching events.

Corkidi, et al. 2010 at the University of California, Riverside and International Plant Propagators Society found that mycorrhizal plants grown in half and full rate of fertilizer were significantly larger than non-mycorrhizal plants. The authors also found that shoots from mycorrhizal plants averaged 30 percent higher nitrogen content and a whopping 300 percent higher phosphorus content than shoots of non-mycorrhizal plants. Perhaps more importantly, the authors documented a significant reduction in the nitrates, ammonium and phosphate found in leachates for the full rate of fertilization. Ammonium and phosphate losses were reduced 30 percent with mycorrhizal inoculation.

In other recent research (van der Heiden et al. 2010,) AM fungi-inoculated soils lost 60 percent less phosphorus and 7.5 percent less ammonium compared to control areas without AM fungi. Similar results were obtained for areas planted with each of three different plant species. In research by Rinaudo et al. 2010, the authors note that "previous work has emphasized that AM fungi are important for the sustainability of agricultural ecosystems by enhancing crop nutrition by providing protection against stress and disease and by improving soil structure."

## WEED SUPPRESSION

In their new study, Rinaudo et al. 2010, explore another positive impact of AM fungi: the ability to suppress negative consequences of aggressive agricultural weeds. It has been estimated that annual crop yields around the world are reduced 10 to 30 percent.

## WHAT WAS DONE & LEARNED

Rinaudo et al. write that they "investigated the impact of AM fungi and AM fungi diversity (three versus one AM fungal species) on weed growth in experimental microcosms where a crop (sunflower) was grown together with six widespread weed species." The four researchers go on to state that: "the total biomass of sunflower grown alone in monocultures was 22 percent higher compared to microcosms where sunflower was grown in mixture together with weeds," while "the total weed biomass in microcosms with sunflower was on average 47 percent lower in microcosms with AM fungi, compared to microcosms without AM fungi." And when the weeds were grown alone, the effect of AM fungi presence was to reduce weed biomass by 25 percent.

*Example of MycoApply Mycorrhizal inoculated onions at left compared to controls on right.*

## WHAT IT MEANS

Rinaudo et al. say their study shows that "AM fungi have the ability to suppress the growth of some aggressive agricultural weeds, including *Chenopodium album* and *Echinochloa crus-galli*, which belong to the top ten of the world's most aggressive weeds." In addition, they note that the sunflower plants they grew "benefited from AM fungi through improved phosphorus uptake," which "points to a novel characteristic of the mycorrhizal symbiosis, namely that AM fungi have the ability to suppress unwanted weed species, while at the same time promoting nutrition of the target crop species." They note that their findings "supports two earlier reports by Vatovec et al. (2005) and Jordan and Huerd (2008)." And in further comments, they state that "sunflower obtained 48 percent more phosphorus when AM fungi were present, while fungi reduced weed phosphorus content of the three non-mycorrhizal weeds (*Digitaria sanguinalis*, *Echinochloa crus-galli*, *Setaria viridis*) by 21 percent."

## DOES MY FARMLAND HAVE MYCORRHIZAE?

Certain modern agricultural practices are known to suppress biological activity in soils. Land clearing, fungicides, certain chemical fertilizers, cultivation, compaction, isolation from natural area, soil erosion, organic matter loss and periods of fallow are all factors that can contribute adversely to populations of beneficial mycorrhizal fungi. Soil testing worldwide indicates that many intensively managed crop and pastures lack adequate populations of mycorrhizal fungi.

Basically, loss of naturally occurring mycorrhizal fungi comes about in three fundamental ways:

1. Fallow soil is among the biggest causes for the demise of mycorrhizal fungi. The fungi are dependent on their host plants for sustenance and cannot survive for any extended duration without the presence of living roots.

2. Tilling, which by itself may adversely affect mycorrhizae, generally leads to fallow conditions, which in turn, impacts the fungi. Therefore, even no-till practices may not necessarily preserve mycorrhizae either. When annual crops are harvested, the roots soon die and any mycorrhizal fungi die with them unless new living roots are introduced in the form of another crop within several weeks. One might think that the spores left in the soil would regenerate the mycorrhizal populations in the next crops planted even after an absence of living roots and hyphae. However, for annual crops, few if any spores develop in one year and after repeated cycles that include regular intervals of fallow, those few spores that are present eventually expire and are not sufficiently replaced by the gradually diminishing mycorrhizal populations.

3. The other critical situation that eventually eliminates mycorrhizal populations from many agricultural lands is lack of proximity to natural populations from which new colonization usually spreads. The crop plants become isolated from the beneficial mycorrhizal fungi that would, in natural ecosystems, be abundantly available to spread colonization to their roots. Without adjacency to natural areas acting as a source of mycorrhizal hyphae and spores to repopulate depleted lands, arbuscular mycorrhizal populations are very slow to re-establish.

Arbuscular mycorrhizal fungi produce their spores below ground and do not move readily via wind or water, but rather grow from root to root. Therefore re-colonization across long distances back into farm soil from undisturbed natural sites becomes slow and difficult. Unfortunately, growing crops immediately adjacent to undisturbed natural ecosystems is not always an option in modern agriculture.



## LIVING SOIL

From the food we eat, to the air we breathe, to the clothes we wear, humans depend upon the thin covering of the Earth's surface we call soil. Arguably this thin and fragile layer of living topsoil is the Earth's most critical natural resource. Lately there has been tremendous interest from farmers about using soil biology, the evolutionary revolution that brought plants to land 460 million years ago, to increase crop yields while protecting and improving our valuable soil resource.

The predicted increase in world population and the inevitable global surge in demand for food, feedstocks and biofuels will require a shift toward more sustainable, biological farming methods. Worldwide fertilizer and herbicide costs have already increased dramatically over the past five years and farmers may be finding themselves relying less on synthetic chemicals to grow crops. Mycorrhizal inoculation offers a great solution to a more efficient use of fertilizers and as a weed suppressant. More and more growers are finding that they can reduce their fertilizer and water costs up to 30 percent while increasing yields by inoculating with mycorrhizal inoculum, an evolutionary success story that is starting a revolution in our thinking today.

Dr. Mike Amaranthus has been working with mycorrhizae for 34 years as a USDA research soil scientist, adjunct associate university professor, and lead scientist for Mycorrhizal Applications, Inc. He has published over 80 research papers on the use of mycorrhizal fungi and been featured on several national and international television specials. Tools, articles, pictures and video using mycorrhizal inoculum are available at *www.mycorrhizae.com.*

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