Inoculate with Mycorrhizae
It's as easy as A-B-Seeds

Fig 4. Root and hyphal threads

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It might be a revelation to most people that plants in their natural environments do not have roots. Strictly speaking they have mycorrhizae. Yes, 90 percent of the world's plant species form mycorrhizae in their native habitats. This "symbiotic" or mutually beneficial relationship is nothing new. Mycorrhizal fungi have co-evolved with plants and soils for over 460 million years. The bottom line is that the mycorrrhizal relationship is as common to the roots of plants as chloroplasts are to the leaves of plants. Plants use leaves to fulfill their carbon needs and mycorrhizal fungi to attain nutrients and water. Why is this important to farmers? Cropping systems could be more sustainable with management of mycorrhizal fungi for increased yields and less reliance on agrochemicals.

In previous *Acres U.S.A.* articles, we have learned about the fungal-plant symbiosis in some detail, become aware of the numerous and valuable benefits afforded crop plants by the mycorrhizal association and explored how to determine whether or not the fungi are present in pastures or croplands. Now we will focus on the A-B-"Seeds" of inoculating with mycorrhizae. Specifically we will explore methods and management that will restore, maintain and enhance mycorrhizal activity on the farm.

Literally thousands of research papers have been written on mycorrhizal fungi, and farmers are becoming well-versed on the benefits. Numerous brands of commercial mycorrhizal inoculums are available but, unfortunately, some have been marketed as a "silver bullet" that will cure all your farm problems. For experienced farmers who already know how to grow crops, we'd like to share with you how to grow them even better.

Mycorrhizal fungi are keystone species anchoring a truly healthy soil that contains a prodigious abundance of biological activity. One heaping tablespoon of healthy soil may contain billions of soil organisms. Just an ounce can contain numbers of organisms equal to the earth's entire human population! An acre of healthy topsoil can contain a web of life that includes 900 lb of earthworms, 2,500 lb of fungi, 1,500 lb of bacteria, 130 lb of protozoa, 900 lb of arthropods and algae, and in most cases, even some small mammals. This plethora of soil organisms equates to billions of miniature bags of fertility, each storing nutrients in its body tissue while slowly converting them into plant-available forms.

"A" QUICK BACKGROUND

Just to review, "myco" means "fungus" and "rhizae" means "root," and so the word "mycorrhizae" means "fungus-roots." In these mutually beneficial partnerships, the root of the host plant provides a convenient substrate for the fungus, and also supplies food in the form of simple carbohydrates. In exchange for

Fig 2. Mycorrhizal powder and mycorrhizal liquid.

Fig 3. Mycorrhizal spores and spores in roots.

this free "room-and-board," the mycorrhizal fungus provides several benefits to the host plant.

A mycorrhiza (the plural is *mycorrhizae*) is an anatomical structure that results from a symbiotic association between soil fungi and plant roots. In exchange for a "home," the fungus provides numerous benefits to the host plant. Mycorrhizal fungi produce an extensive network of microscopic hyphal threads that extend into the surrounding soil or growing medium. The group of mycorrhizal fungi that are most important to agriculture are called arbuscular mycorrhizal fungi (AMF or sometimes endomycorrhizal fungi). These fungi are found on the vast majority of agricultural plants with the exception of canola, the cabbage family, spinach and sugar beets. AMF also form mycorrhizae with a wide variety of wild and cultivated plants including most grasses, tropical plants, and most fruit and nut trees.

COMMERCIAL MYCORRHIZAL INOCULANTS

If you have determined that your crop or pasture roots are well colonized with mycorrhizal fungi, congratulations! You may skip ahead in this article to the section that reviews methods that help maintain or enhance mycorrhizal activity and populations. However, if your land has been repeatedly tilled or left fallow or if root colonization analysis of your crop or pasture plants indicates low levels or absence of mycorrhizal colonization, you will find re-establishing and rebuilding effective populations can be relatively easy and cost effective (see Figure 2).

The fastest, most effective way to restore depleted mycorrhizal populations in croplands or pastures is to apply a commercial mycorrhizal inoculant to the roots or seeds. The technology in commercial inoculants has advanced tremendously in recent years. Many inoculants are viable for up to two years or more, remain tolerant of temperatures from well below freezing up to 140˚F, and are compatible with most fertilizers and pesticides. Modern inoculants are available in diverse forms such as granular, powder and liquids to accommodate a variety of equipment and application methods.

"B" WITH SEED

Benefits are maximized when the mycorrhizal fungus colonizes the roots as early in the plant's life as possible. In a perfect world, this is immediately after the seed has germinated and begun to sprout. The active components in the inoculum are mycorrhizal fungi propagules in the form of spores and colonized root fragments (see Figure 3). When one of these colonizing units touches or comes into very close proximity of living root tissue — in this case the sprouted seed, they are activated by minute amounts of specialized root exudates and begin the mycorrhizal colonization process.

Within a brief period ranging from a few days to a few weeks, the newly colonized root cells begin to send hyphal threads from the young plant's roots. The hyphae then begin absorbing moisture and nutrients from the surrounding soil while warding off root disease pathogens via production of antagonistic exudates. These processes result in greatly improved chances for survival compared to non-mycorrhizal plants. Almost immediately, the colonized sprout develops special "tools" to secure adequate moisture, nutrients and defense against fungal root diseases. The hyphae quickly grow and spread throughout the surrounding soil, penetrating the tiny spaces between soil particles (see Figure 4). As they encounter more roots, these also become colonized. Then, each of these roots produce more hyphae which, in turn colonize even more roots until a massive hyphal network has pervaded the expanded rhizosphere. Clearly, inoculating seeds with mycorrhizae is an effective way to go. The benefits are the greatest and the cost is minimal, since treating a seed usually takes less inoculum than is required to colonize the larger root system of a more developed plant.

Seed treatment is best accomplished using either powdered or liquid mycorrhizal inoculants applied so that the inoculum adheres directly to the surface of the seed. Powdered inoculants work well with hairy-textured seeds such as wheat, barley, oats or many grass seeds. Seed adhesion is important not only to insure inoculum proximity to the germinating seed, but because excess powder falling off the seeds can accumulate in the seed box, possibly leading to mechanical problems with the auger and drill operation of the planting equipment.

A liquid inoculum is often preferred for corn, beans, alfalfa and similar smooth-surfaced seeds because it will adhere well. A "sticker" or tackifier product is necessary to apply powdered inoculants to these types of seeds to keep the powder attached to the seed surface. Inoculum application can also be accomplished using specialized seed-treating equipment, a service often provided by seed or agronomy suppliers. Alternatively, many growers treat their seed on the farm using cement mixers or by lightly spraying liquid inoculum on the seed as it passes on the conveyor to the seed box on the planter. If done carefully, simply stirring in a powdered inoculant as seed is placed in the seed box and allowing the augers to further distribute the inoculant onto the seed will suffice. Often a liquid inoculum can be applied to seed by mixing it with other seed treatments such as legume inoculants on beans, alfalfa and vetch.

THE NEAR-SEED EXPERIENCE

If one or more factors such as equipment limitations, excessive seed handling, physical seed properties, etc. preclude the seed application methods suggested above, there are yet other viable methods available to place the mycorrhizal inoculum on or near the seed. A liquid mycorrhizal inoculum can be sprayed in-furrow alone or with other liquids. In some cases, a granular inoculum can simply be mixed with the seed in the furrow. Another method involves shanking or banding a granular inoculum a few inches below and/or to the side of the furrow. While this latter technique does not inoculate the seed immediately upon germination, the young plants become colonized as their roots enter the treated bands. This latter method often dovetails well with fertilizer or other planting process applications.

GETTING TO THE ROOTS

Establishing root colonization using commercial mycorrhizal inoculants is not limited to seed treatment or to the crop planting process. Plants may also be treated

after planting, including established crops and pastures. In these situations, the method employed is to shank or knife-in a granular inoculant in the soil adjacent to the growing crop. In this situation, the roots become colonized when they eventually enter the treated soil. This kind of application is not uncommon among vegetable row crops grown from young transplants. Treating established crops is particularly worthwhile with perennial crops such as alfalfa in which a one-time inoculation will continue to deliver benefits over several years. The amount of inoculant used to treat such a crop is greater (and therefore also the cost) but the advantages apply to multiple harvests. Forage pastures are another excellent example whereby either a one-time or a few incremental applications can afford very long-term benefits.

Yet another way to restore mycorrhizal colonization to perennial or permanent grass crops such as hayfields or pastures is to simply use inoculant-treated seed when over-seeding. The treated seed will quickly colonize and spread the fungi to surrounding roots. After a few over-seeding repetitions, the cumulative effects will have thoroughly colonized the field.

"C"HOOSING AN AM INOCULANT

Base your choice of mycorrhizal inoculant on the crop plant(s), application method (e.g. seed, furrow, etc.), available equipment and other application considerations such as labor. Let the ease of application be your guide when choosing a product. Look for products with long shelf life, good propagule counts and some diversity of AM mycorrhizal fungal species. Although single-species inoculants can be used (*Glomus intraradices* is the most commonly used), results are often enhanced by inclusion of multiple species (see Figure 5a and 5b). Application rates may vary depending on the concentration of propagules in an inoculum and, of course, the crop, seed or plant spacing and other factors. Essentially, application rates are based upon placing sufficient numbers of spores on or near seeds or roots to ensure fast and effective colonization throughout the crop.

MINDING YOUR "P'S"

When applying a mycorrhizal inoculant at planting, it is important to avoid high levels of available phosphorus in the soil proximate to the target seed or roots. Readily available soil phosphorus in excess of approximately 70 ppm can prevent the mycorrhizal spores in an inoculant from breaking dormancy when in near contact with a live root. Since one of the primary natural functions of the mycorrhizal relationship is to access and mobilize phosphorus, the spores have been "programmed" to delay activation in an abundant phosphorus environment. The propagules are not harmed and do not expire under such circumstances, however they remain dormant and colonization does not commence until the ambient phosphorus levels diminish. Insoluble forms of phosphorus, such as phosphates of aluminum, iron, calcium or magnesium which may naturally occur in soils do not contribute to this phenomenon. Likewise phosphorus from organic or natural fertilizers such as soft rock phosphate, manures, humates, fish fertilizers or kelp are not problematic. It is *readily available* phosphorus, derived primarily from soluble (liquid) or fast-release fertilizers that contributes to this situation. The solution is to avoid high rates of P starter fertilizers. Remember that one of the primary reasons for high P in starter fertilizers is to overcompensate for the inefficiency of non-mycorrhizal roots. Once crop plants become colonized with mycorrhizal fungi, these high P levels are no longer required. Phosphorus fertilizers applied anytime 10 to 20 days *after* inoculation and colonization has occurred need not be restricted. Note however, due to the greatly improved phosphorus uptake efficiency imparted by the mycorrhizal association, amounts of P fertilizers needed for good crop performance may be noticeably reduced.

Fig 5. Sorghum trial planted with (left) single species mycorrhizal inoculum and multiple species mycorrhizal inoculum.

HOW DO I KNOW THE MYCO IS WORKING?

How does one tell if an application of a commercial mycorrhizal inoculant is working? First off, as in trialing any change in program, be sure to leave a part of your crop untreated as a control. Often the effects of mycorrhizal colonization will be obvious in early growth. The plants may be taller, have more foliage and larger root systems (see Figure 6). If water is scarce, you may note less moisture stress compared to controls. Sometimes the visual difference between the treated and the control crop is less obvious but the yields are significantly better in the treated crops. And occasionally, there will be no discernable difference at all. In this last circumstance, it may be that the benefits lie entirely in savings via reduced inputs to get the same yields as without treatment. Capitalizing on this may take some experimenting over several seasons.

MYCORRHIZAE MAINTENANCE

Once you have re-established mycorrhizae on your crops, there's not much that will remove them from the living

roots, but there are a lot of things that will help them colonize quicker, more thoroughly and increase the density of the hyphal network. What do compost, compost teas, no-till methods, humates, seaweed extracts and fish fertilizers have in common? All of them, in diverse and various ways, increase the microbial activities in soils, including the mycorrhizal fungi which then spread from root to root faster and further enhance the nutrient uptake efficiency of the colonized plants.

A, B, SEEDS

Scientific research confirms that fallow, frequent tilling, erosion, compaction and high levels of soil phosphorus availability delay, reduce or eliminate the soil's mycorrhizal fungal populations. Advancements in our understanding of mycorrhizal fungi and their requirements has led to the production of concentrated, high-quality mycorrhizal inoculants available in granular, powder, and liquid forms making application more convenient.

The most important factor for re-integrating mycorrhizae into the cropland environment is to place mycorrhizal propagules near seed or near the root systems of target plants. Granular inoculum can be banded with seed or seedlings. Powdered forms of inoculum can be mixed with seed before or during sowing. Liquid forms can be sprayed on seed and in-furrow, or drenched "over the top" for existing crops in porous soils. The form and application of the mycorrhizal inoculum depends upon the grower's needs and equipment and is as easy as A,B, Seeds.

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