The Application of Mycorrhiza in Production Improvement of Crop Plants

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ABSTRACT

Mycorrhizal fungi form symbiotic associations with the young fine roots of many plant species. Arbuscular mycorrhizal (AM) fungi form associations with 70% of flowering plants as well as many ferns and conifers, and constitute an estimated 70% of the microbial biomass in most undisturbed soils. They can only survive in the presence of a live host. Mycorrhizae supply their hosts with mineral nutrients (notably phosphorus) in exchange for energy compounds. Arbuscular mycorrhizal (AM) fungi dramatically increase the volume of soil from which plants are able to draw nutrients. AM associations at a particular root site only last for 5 to 6 days but are continually reforming closer to the root tip as the roots elongate. In healthy ecosystems the large amount of infective mycorrhizal propagules (hyphae, spores etc) quickly recolonise plant roots when relationships are disturbed. However, there are many land management practices that can severely deplete and sometimes extinguish mycorrhizal populations. These include overgrazing; changing plant community composition to less mycorrhizal plant species such as annuals; ground disturbance such as ploughing and laser levelling; and removal of host plants e.g. fallow practices. This paper focuses on a discussion of these management practices and their consequences for ecosystem health and farm productivity.

INTRODUCTION

Mycorrhiza is a mutualistic association between fungi and higher plants [1]. Different types of mycorrhizae occur, distinguished by their morphology and to a certain extent, in their physiology. These include the ectomycorrhizae and endomycorrhizae. The ectomycorrhizae characterized by an external sheath of fungal cells surrounding the root, often penetrates between the cells of epidermis and the first few cells of cortex and the fungal hyphae typically infect the roots of forest trees of the temperate region. While endomycorrhizae like vesicular arbuscular mycorrhizal (VA) fungi form no sheath, the fungus infects the root system of most cultivated crops and usually it invades several layers of the outer root cortex. VA-fungal hyphae penetrate individual cells and form arbuscules within the cell and vesicles outside their host cells which led to their name [2]. Vesicular-arbuscular mycorrhizal (VA) fungi colonize plant roots and ramify into the surrounding bulk soil extending the root depletion zone around the root system. They transport water and mineral nutrients from the soil to the plant while the fungus is benefiting from the carbon compounds provided by the host plant. Therefore VA-fungi have a pervasive effect upon plant form and function [3]. Little is known about the natural ecology of these fungal-plant associations and the effects of certain soil amendments with natural waste products. VA-fungi are associated with improved growth of many plant species due to increased nutrients uptake, production of growth promoting substances, tolerance to drought, salinity and transplant shock and synergistic interaction with other beneficial soil microorganisms such as N-fixers and P-olubilizer [4]. Symbiotic association of plant roots with VA-fungi often result in enhanced growth because of increased acquisition of phosphorus (P) and other low mobile mineral nutrients [5]. Effective nutrient acquisition by VA-fungi is generally attributed to the extensive hyphal growth beyond the nutrient depletion zone surrounding the root [2]. Although a lack in growth response to VA-fungi inoculation in unsterilized soil was also recorded, this result has been attributed to the fact that native VA-fungi may provide the potential benefit of this mutualistic association [6]. It was reported that one of the principal avoidance strategies of plants for adaptation to adverse soil conditions is an increase in root surface area via mycorrhizae [7]. A better understanding of
themycorrhizae of agronomic crops is needed because of their potential involvement in systems of sustainable agriculture [8].

**Significance of VA Mycorrhizae:**

**Mineral nutrition:**

Phosphorus: The major role of VA-fungi is to supply infected plant roots with phosphorus, because phosphorus is an extremely immobile element in soils. Even if phosphorus was added to soil in soluble form, it becomes immobilized as organic phosphorus, calcium phosphates, or other fixed forms [9, 10]. VA-fungi are known to be effective in increasing nutrient uptake, particularly phosphorus and biomass accumulation of many crops in low phosphorus soil [11]. Several investigators indicated that there is a beneficial effect of VA-fungi inoculation on nutrient uptake and on plant growth especially in sterilized soils [1, 12-13]. In white clover (Trifolium repens L.), mycorrhizal inoculation doubled the concentration of phosphorus in shoots and roots of infected plants and increased their dry weight [14]. Also Al-Karaki et al., [15] indicated that shoot dry matter, shoot phosphorus and root dry matter were higher in mycorrhizal infected wheat (Triticum aestivum L.) plants than for non-infected plants. On the other hand, mycorrhizal infection has been shown to depress plant growth in soils with optimum phosphorus availability, these effects were attributed to competition for carbon between the host plant and the mycorrhizal fungi [11].

**Nitrogen and micronutrients:**

The enhanced effect of VA-fungi on the uptake of nitrogen and micronutrient uptake may be attributed to two situations. In the first one, mycorrhizal hyphae act as extension to plant root, increasing root surface area and exploring larger soil volume, which will increase the chance of more micronutrient uptake. Mycorrhizal association with plant roots may also enhance translocation between root and shoot of the infected plant, hence enhancing the plant growth [11]. At low phosphorus levels in soil, mycorrhizae substantially increases copper and zinc contents of the shoot. However, it was found in case of soybean (Glycine max L.), grown in high phosphorus levels soils, the mycorrhizae decreases copper and zinc contents of infected plants [16]. Peanut (Arachis hypogaea L.) plants grown in sterilized soil without VA-fungi inoculation developed visible symptoms of phosphorus and zinc deficiency [17].

**Relationships between Biofertilizers and Mycorrhizal Fungi:**

Plant roots secrete “food” for bacteria and fungi, which attracts nematodes (worms) to theroots, because nematodes eat bacteria and fungi, and excrete Nitrogen, sulphur and phosphorus in a form that the plants can use [18]. The nematodes only keep 1/6 of the nitrogen that they process, –5/6 is excreted to the plant. Once the nematodes have excreted the nutrients, the hyphae of the mycorrhizal fungi pick them up and transfer them into the plant. Because of this symbiotic relationship, the least-leachable form of Nitrogen you can apply is bacteria and fungi, and bacteria are the most Nitrogen-rich organisms on earth [18]. AM hyphae pick up more nutrients than just those excreted by nematodes, however. One of the most beneficial properties of AM mycorrhizae is its ability to “mine” the soil great distances from the roots for nutrients, especially those, such as Phosphorus, that are poorly mobile in the soil. AMMycorrhizae also assist in picking up water further away from the roots, and block pest access to roots [19]. Mycorrhizae also benefit plants indirectly by enhancing the structure of the soil. AM hyphae excrete gluey, sugar-based compounds called Glomalin, which helps to bind soil particles, and make stable soil aggregates. This gives the soil structure, and improves air and water infiltration, as well as enhancing carbon and nutrient storage [19].

**Effect of soil fertility on mycorrhizal infection:**

Most authors report extensive colonization to occur mainly in plants growing in soils of low fertility. Field and greenhouse studies demonstrated that crops growing in nutrient-poor soils had higher levels of mycorrhizal colonization than crops growing in better soils. Vascular-arbuscularmycorrhiza inoculation in combination with phosphorus increased dry and fresh shoot weight, leaf area and leaf number of strawberry compared to application of phosphorus alone.

**VAM and soil fertility:**

Three main components are involved in VAM association: 1) the soil, 2) the fungus and 3) the plant. The fungal component involves the fungal structure within the cell of the root and the extraradical mycelium in the soil. The last may be quite extensive under some conditions, not form any vegetative structures. Its primary function is the absorption of resources from the soil. The increased efficiency of mycorrhizal roots versus nonmycorrhizal roots is caused by the active uptake and transport of nutrients by mycorrhizae. Mycorrhizae are described as improving the absorption of several nutrients as indicated in. Inoculation with *Glomus mosseae* not only affected plant growth and nutrition in *Medicago sativa*, but also enhanced the activity of *Rhizobium meliloti* when it was applied as an inoculant. AMF have been shown to improve productivity in soils of low
fertility and are particularly important for increasing the uptake of slowly diffusing ions such as PO4 3-, immobile nutrients such as P, Zn and Cu and other nutrients such as Cadmium. Under drought conditions the uptake of highly mobile nutrients such as NO3- can also be enhanced by mycorrhizal associations. In legume plants the importance of AMF symbiosis has been attributed to high P requirements on the nodulation and N2 fixation process which requires enhanced P uptake. Improved P nutrition has been shown to increase in infertile and P-fixing soils of the tropics. Mycorrhizal fungi can also improve absorption of N from NH4+ -N mineral fertilizers, transporting it to the host plant. Its transport and absorption can also increase biomass production in soils with low potassium, Calcium and Magnesium [20].

Effect of mycorrhiza in fertile soil:

Mycorrhizal fungi form a symbiotic association with the roots of most plants. The fungi grow into or between the cells of the roots and use ten percent of the carbohydrates the plant passes from the leaves to the roots. The fungi do not have chlorophyll in the presence of sunlight, so they can't manufacture carbohydrates. In return for the energy taken from the plants, the fungi grow out and search far and wide for nutrients and moisture. They feed the plant so it can continue to manufacture more and more carbohydrate energy. A plant well colonized with mycorrhizal fungi will have the equivalent of ten times more roots than one without the fungi. Another benefit of this association is that, as long as the fungi is flourishing, it can prevent all root pathogens and damaging nematodes from attacking the plant root. Decaying organic mulch on the soil keeps both the plant and the many beneficial soil species, such as the mycorrhizal fungi, flourishing so they can help each other. The appearance of mycorrhizal fungi was reported in 1885 by a German botanist, A. B. Frank, who believed that water and soil nutrients might be entering trees through these fungi. This fungus acts as a link between the soil and rootlets of the plant. It flourishes in humus. When the association is present, plants are strikingly vigorous, achieve good growth, and gain resistance against attacks by insects and diseases. Among forest trees and other plants, including food crops, the mycorrhizal association is widespread, habitual, and at times essential. It is stimulated when there is ample light, adequate pH of the soil, good aeration, humus and moderate soil fertility. It is inhibited by the presence of many chemical fertilizers. It has been found that these fungi can play an important role in plants grown in infertile soils where phosphorus, zinc, and copper are especially scarce. Mycorrhizae assist tree growth in such soils. As the plants prosper, so do the fungi, since they depend on food from the plants for their own energy. They use about 10% of the carbohydrates the plant passes from the roots for their own energy. They use about 10% of the carbohydrates transported from plant leaves to the roots. The efficient system works as follows: As plant roots grow, they encounter hyphae, a network of tiny, thread-like tubes. The hyphae seek out nutrients that are poorly available in the soil areas unexplored by the roots. Hence, the root system is extended by the fungi, since the hyphae enable the plant to explore more areas and to obtain more essential nutrients in useable solution forms than could be possible otherwise. Within the root, the fungus forms two different structures: vesicles and arbuscules. The former are round, balloon-like structures that store carbohydrates from the roots. The latter are highly branched structures that accumulate nutrients, absorbed by the hyphae, that can be released to the plant. In studies at Ohio's Agricultural Research and Development Center, it has been learned that the more fertile the soil, the less need there is for mycorrhizae. Also, it has been found that certain fungi perform nutrient-uptake function better than others. By inoculating apple seedlings with an effective mycorrhizal fungi before planting, growth is stimulated. The practical beneficial effects of mycorrhizae have been demonstrated convincingly in different parts of the world. Attempts to reforest areas, which failed because of a lack of mycorrhizal fungi, became successful after the soil was inoculated with pure cultures of mycorrhizae-producing fungi or with soils taken from an old forest stand. In the U.S.S.R., for example, certain steppes have been re-forested with oak, after it was found that seedlings inoculated with mycorrhizal fungi were able to resist the extreme climatic conditions. Similarly, high mountain regions of Austria were successfully reforested with spruce by means of mycorrhizae. In the United States, experiments of prairie soil inoculation produced beneficial effects on poplar cuttings, with better growth and higher survival rate. White pine seedlings cultivated in inoculated prairie soil contained 86% more nitrogen, 230% more phosphorus, and 75% more potassium than plants in untreated soil. It
has been demonstrated that mycorrhizal associations unlock food elements from the soil. In experiments, pine seedlings with the fungus had four times as much phosphorus as pine seedlings without it. Mycorrhizal association is of prime importance in tree nurseries and plantation practices. But it is also important to a variety of other plants too, including many cultivated food crops such as cereal grasses, legumes, fruit trees, and berries.

**Effects of VAM on Drought and Salinity Stress:**

Drought stress is a major agricultural constraint in the semi-arid tropics. It is known to have a considerable negative impact on nodule function. Drought inhibits photosynthesis and disturbs the delicate mechanism of oxygen control in nodules. The latter is essential for active nitrogen fixation. AMF symbiosis can protect host plants against detrimental effects caused by drought stress. Quilambo reported that inoculation with an indigenous inoculant resulted in increased leaf and root growth and prevented the expected increase in root to shoot ratio and root-weight ratio that are normally observed under phosphorus deficient and drought stress conditions in peanut. In watermelon (Citrulluslanatus Thunb.) mycorrhizal colonization was found to improvent only the plant yield and water use efficiency, but also the quality of the fruit [21].

Several mechanism have been proposed to explain the protection of AMF symbiosis, such as changes in plant hormones, increased leaf gas exchange and photosynthetic rate direct hyphal water uptake from the soil and transfer to the host plant, enhanced activity of enzymes involved in anti-oxidant defense, nitrate assimilation enhanced water uptake through improved hydraulic conductivity and increasing leaf conductance and photosynthetic activity [22, 23], osmotic adjustment and changes in cell-wall elasticity. Often mycorrhizal improvement of drought tolerance occurs via drought avoidance. It can be a function of the often observed improved acquisition of phosphorus, nitrogen and other growth promoting nutrients by AMF plants [24]. According to Fitter the influence of AMF on water uptake and transport may be a secondary consequence of enhanced host phosphorus nutrition, although these effects are not consistent [25]. AMF can also reduce the impact of environmental stresses such as salinity. In Azadirachta indica with increased salinity level, there was decrease in percent of root infection by AMF [26].

REFERENCES


