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THE IMPORTANCE OF MYCORRHIZAE IN MICROBIOLOGY AND HOW IT RELATES TO FOOD SECURITY

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Abstract. *Many plant species are mycorrhiza-dependent in terms of soil fertility level and plant species genetics.*

Arbuscular mycorrhizae fungi (AMF) have a significant impact on better soil health, crop rotation, plant and soil biodiversity, sustainable agriculture development, plant species disease resistance, improved soil structure development, mineral nutrient and water uptake, and carbon sequestration. These collaborations affect soil structure and carbon sequestration as well. By increasing the root-absorbing surface area, mycorrhizal fungi efficiently absorb important immobile nutrients like phosphorus, zinc, copper, and nitrogen, especially in nutrient-poor soils. In addition to helping with nitrogen fixation, mycorrhizae also aid in nutrient cycling and plant health. Mycorrhizal fungi are crucial elements of soil microbiology that have a big impact on food security. AMF help the plant by reducing chemical fertilizers and biocides to get maximum benefits. In this way, plant species especially plants whose fruits and tissues are edible get practical benefits for farmers. They promote soil fertility, raise soil stability, improve plant health, and enhance nutrient uptake, all of which support sustainable farming practices. Understanding and encouraging these symbiotic interactions can lead to more robust and efficient food systems, which are required to meet the rising global demand for food while minimizing environmental effects. The impacts of greenhouse gases, which cause climate change, can be lessened with the aid of mycorrhiza.

It has been shown after extensive research that the function of mycorrhizae varies according to how the soil and plants are managed by mycorrhizal fungi. It has been found that, in long-term field tests, the use of mycorrhizal fungus and soil-plant management techniques boosted the growth and nutrient intake of many plants. Contribute to reducing fertilizer use as well. This paper aims to provide an overview of the soil organisms, especially AMF as a bio fertilizer and bio stimulant and their effect on growth and nutrient uptake.

Keywords: *Rhizosphere, Mycorrhizae, Nitrogen fixation, Soil Fertility, Plant nutrition,*

Introduction

The world population in the last 100 years increased from 2 billion to 8 billion. Human food demand increased and in the next 50 years need is going to double as well. Agriculture is highly dependent on ecological variables such as climate and soil conditions. In many world areas, soils are poor in organic matter and nutrients, the water is scarce and the risk of salinization and aridisation is high. On the other hand, the effects of climate change make agricultural production more limited and capacity challenging. The evolutionary development of plants over thousands of years in nature and the mechanisms they have acquired against the soil and climate conditions still provide strong food production. The most important of these mechanisms is the relationship between plants and soil microorganisms in the root zone. Microorganisms play an important role in plant, soil and environmental sustainability. Numerous plants and microorganisms cannot survive without undergoing association with- friendly relationships. Although we generally have information about bacteria, fungi, actinomycetes, viruses and others from microorganism groups, we know very little about each species' subspecies and total existence. The largest soil microorganism group is fungi. Although approximately 150,000 species of fungi have been described, it is estimated that between 2.2 and 3.8 million exist (Hawksworth and Lücking, 2017). The symbiotic relationship between microorganisms and plant root depends on a bilateral relationship. Symbiotic association between plant roots and fungi is very common among the plant species.

Plant-Soil Mechanism for Nutrient Uptake

Plants that are unprotected and exposed to the environment turn on their adaptation mechanisms to become resistant to abrupt biotic and abiotic stress. Like all other living things, plants have evolved defenses against elements of nature's functioning, like seasonal and climatic variations. The cooperation of plant root secretions and microbial secretions in the presence of various stress factors generates unique, specialized habitats that protect the plants from stress.

In the development and healthy growth of plants in the ecosystem, the complex interaction between soil and roots is crucial. The roles of microorganisms and root secretions create the root-shoot system's greatest carrier structure. The two-way complicated interactions provided by hormones and root secretions allow the plant root and stem to communicate with one another in the case of all types of stress conditions. Recently Shindo and Umehara (2023) indicated that plant roots come into direct contact with the soil environment, but it takes a sophisticated process to determine how much inorganic nutrition is there. By using shoot-to-root or root-to-shoot transportable signals, such as plant hormones and accurate perception of the nutrient levels in the soil, plants can alter their architecture, the expression of nutrient transporters, and the quality of plant-microbe interactions in the rhizosphere. So far, we have not been able to accurately measure the nutrient concentration in the rhizosphere area. Though the mechanism is not entirely known, certain theories can be advanced. Microorganisms take part in the process in any situation and contribute to its smooth operation.

Microorganisms that Benefit Soil/Plant Systems

They can be divided into saprotrophs (which need the organic compounds released by the plant to live) and symbionts (which live intimately with the plant, colonizing the roots without damaging them)

Many saprotrophs and symbionts carry out activities such as:

Stimulating the germination of seeds

Improving rooting

Increasing the availability of nutrients

Improving the soil structure

Protecting the plant from stresses (salinity, drought, nutrient deficiency, heavy metals, pathogens….).

The main symbionts are N2-fixing bacteria (nodules in legumes) and mycorrhizal-forming fungi. Interactions between arbuscular mycorrhizas and other beneficial soil microorganisms are complex. The most significant plant–microbe symbiosis, and arbuscular mycorrhizal relationships are just one facet of the complex microbial interactions that occur in the rhizosphere (Azcon and Barea, 1997).

Mycorrhizae have many other benefits for plants such as;

Promotes uptake of nutrients, especially phosphates.

Enhances plant growth.

Fosters development of healthy seedlings.

Increased yields.

Increases the survival rate of transplanting.

Strengthens plants against environmental stress

Increases the number of flowers.

Soil Fertility Affected by Rhizosphere Organism Interactions.

Plant roots can alter their close environment (in the root-soil interface), called the rhizosphere, by absorbing nutrients and liberating exudate. Nutrient and water uptake, root respiration, root exudate, and pH changes (either increases or decreases) can occur at this thin soil layer. The rhizosphere soil differs from non-rhizosphere soil, chemically, physically and biologically (Figure 1).

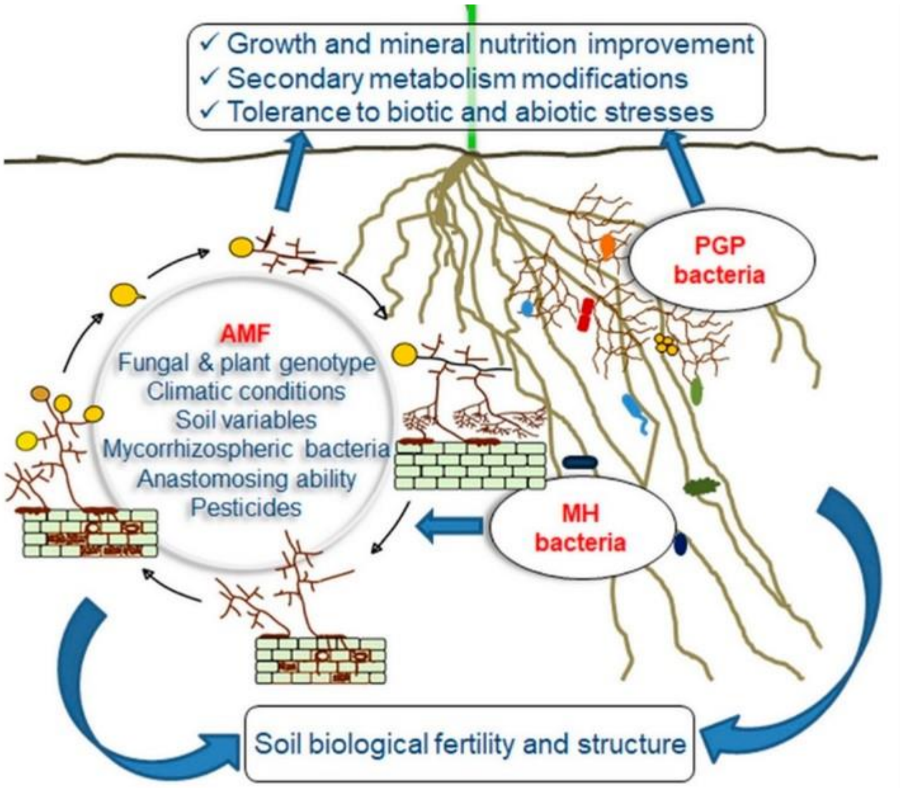


Figure 1. beneficial microorganism and plant interaction on plant growth (Mycorrhiza helper bacteria - Wikipedia; https://en.wikipedia.org/wiki/Mycorrhiza_helper_bacteria)

Agronomic management may also affect the interaction and cycling of nutrients between microorganisms. Irrigation, soil tillage, and fertilizer types and applications have a significant effect on rhizosphere organisms as well. These differences depend on plant species, mineral nutrient supply, and nutrient status of soils. They improve rooting, through the production of hormones, vitamins and other phytoactive substances by the fungi.

The most important interactions developing in the rhizosphere can be classified into three main groups:

1) Plant - plant interactions,

2) root-microorganism interactions,

3) microbe-microbe interactions.

The largest fungi group that has a symbiosis with plant roots is mycorrhizae. All soil organisms in the rhizosphere have a significant influence on soil quality and food quality as well (Figure 2)

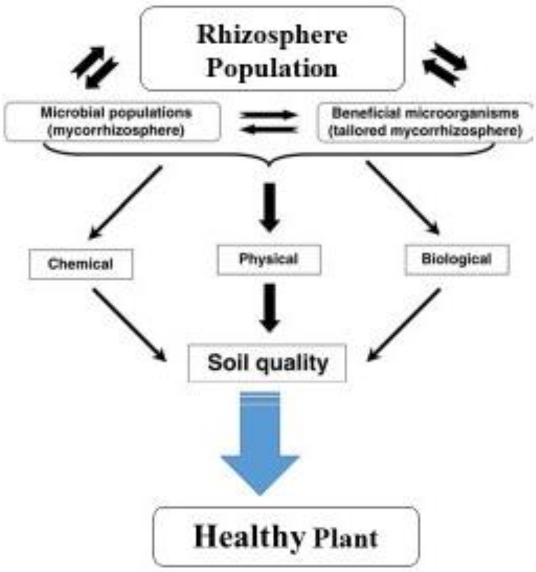


Figure 2. Role of rhizosphere organism on soil quality and plant quality

What is Mycorrhiza and Why Mycorrhiza

Mycorrhizal is a most common mutualistic symbiosis (non-pathogenic association) between soil-born fungi and plant roots (Smith and Read, 2008). The majority of plant species are naturally arbuscular mycorrhizae (AM). About 80% of terrestrial plants, including herbs, shrubs, and trees, are colonized by AM fungus which also creates arbuscules within root cells, including the great majority of species in agroecosystems and natural ecosystems (Smith *et al.*, 2010). Mycorrhizae provide a critical linkage between the plant root and soil. Mycorrhizas are highly evolved, mutualistic associations between soil fungi and plant roots. They improve the diversity of plant communities and plant succession.

The term itself means "fungus root". "myco" = fungus and "rhiza" = root. Several different types of association (defined by the structure of fungus: plant interface). Endo and ecto mycorrhizae are inoculated more than 90% of mycorrhizal plants. As each plant is compatible with a particular type of mycorrhizal fungus, this ensures the conservation of fungal diversity, which in turn benefits the diversity and succession of plants. The Glomeromycota group of fungi includes arbuscular mycorrhizae (AMF) is the major group in endomycorrhiza. Symbiosis is often used to describe these highly interdependent mutualistic relationships where the host plant receives mineral nutrients while the fungus obtains photosynthetically derived carbon compounds.

The role of mycorrhizae in the rehabilitation of decertified ecosystems

Mycorrhizal fungi are important through the following mechanisms:

Enhancing establishment and growth of plants by increasing nutrient uptake.

Contributing to efficient recycling of nutrients and thus to long-term stability.

Stabilizing the soil structure and quality can supply host univariant for many soil organisms including mycorrhizae hyphae.

Because fungi hyphae;

Can access greater soil volume

Can break molecules down into useable forms

Can turn inorganic phosphorus and nitrogen into forms usable by plants.

Recent research suggests that mycorrhizal fungi might be an important component of the SOC pool, in addition to facilitating carbon sequestration by stabilizing soil aggregates.

In an ecosystem, the flow of carbon to the soil mediated by mycorrhizae serves several important functions such as changing the richness of rhizosphere organisms and changing the rhizosphere environments for the availability/solubility of nutrients in minerals from soil. Carbon leaking into the rhizosphere supplies food for all microorganisms, which makes nutrients available to plant species. Measurements of plant carbon allocation to mycorrhizal fungi have been estimated to be 5-20% of total plant carbon uptake (**Pearson and Jakobsen, 1993**) and in some ecosystems, the biomass of mycorrhizal fungi can be comparable to the biomass of fine roots.

The Role of Mycorrhizae is Beyond Soil Fertility and Plant Nutrition

Since mycorrhizas inoculation plants feeding better, they grow bigger as a result, mycorrhizal plants are often more competitive to take nutrients and better able to tolerate environmental stresses than are non-mycorrhizal plants. Their early establishment in the growth process of plants is important. Mycorrhizal symbiosis results in reduced nutrient stress, and also can reduce other environmental stresses such as soil drought, they can benefit plant growth. Since increased nutrient uptake made possible by the AM symbiosis results in more vigorous plants.

Enhance less mobile nutrient absorption

Enhance tolerance of adversity in drought, heavy metals stress, salt stress, high temperature, flooding, diseases and insect pests etc.

Improve fruit quality

Promote plant growth

Modify root development, architecture and root hair

Improve soil structure by producing glomalin and hyphae

Increase soil fertility by dissolving nutrient availability

Increase plant resistance against past and weed plants

Mycorrhizae also play a key role in soil aggregate formation and aggregates can keep carbon in soil. Recent research suggests that mycorrhizal fungi might be an important component of the SOC pool, in addition to facilitating carbon sequestration by stabilizing soil aggregates. Mycorrhizae have a significant contribution to soil stabilization as well. Such situations occur as much in agro-systems (through excessive fertilization, especially phosphate); through the use of non-controlled fungicides and other phytochemicals; or the incidence of abiotic stresses) as in natural ecosystems with the consequence of erosion/desertification. If soil erosion is pronounced, the scarcity of microbial propagules in such ecosystems may be a serious handicap to plant establishment and survival.

Table 1. The effect of single, dual, multiple (cocktail of five species, indigenous mycorrhiza) and a commercial arbuscular mycorrhizal product on shoot and root dry weight of seedlings of sour orange on two growing media (Ortas and Ustuner, 2014).

	Shoot				Root			
	Dry Weight (DW)							
Treatment	GM1		GM2		GM1		GM2	
Control	12.9	±10.72b	11.6	±2.99b	5.06	±2.01b	4.08	±0.55b
Funneliformis mosseae	21.8	±6.76a	18.3	±6.24ab	9.48	±2.57a	6.52	±3.14ab
Funneliformis caledonium	23.1	±13.36a	15.2	±3.44ab	11.41	±6.68a	9.97	±7.06ab

Claroideoglomus etunicatum	19.1	±12.80a	19.2	±3.60ab	7.09	±5.01a	7.30	±1.68ab
Indigenous mycorrhiza	23.1	±7.34a	26.3	±1.77a	9.15	±2.95a	14.81	±1.76ab

Growing medium (GM1) consisted of andesitic tuff + peat (1:1 (V: V),
Growing medium (GM2) consisted of andesitic tuff + peat + soil (4+5+1) (V: V: V).

In such cases, it may be necessary to inoculate with indigenous fungal species or augment the natural AMF already present within the rhizosphere of indigenous leguminous plants. When degradative processes have affected the propagules of mycorrhizal fungi, it is necessary to introduce them to the plants during the key stages so that they can form symbioses. In such cases, it is necessary to produce mycorrhizal inoculum, which can be conveniently applied. The inoculant needs to be appropriately selected, of suitable quality, formulated and assayed for infectivity. It has been tested that the effects of indigenous mycorrhizae on citrus seedling (Tabel 1) are highly effective and significantly increased growth (Ortas and Ustuner, 2014).

Bacteria and Fungi Relationship in Rhizosphere

The rhizosphere is defined as "that zone of soil extending from the root-soil interface to that point in the soil where the microflora is unaffected by the root" (Rovira *et al.*, 1983). It alters nutrient availability and nutrient uptake pathways, which has an impact on plant nutrition. The rhizosphere is likely to benefit plants as a result of the presence of AM and other soil microbes. The nature of root exudates, which can alter the rhizosphere, allows the plants to control the microbial population, including mycorrhizal fungus.

The existence of soil bacteria is also supported by a variety of chemical substances. The growth of bacteria in the rhizosphere is also influenced by the kind of root. In light of this, plant roots discharge carbon molecules into the rhizosphere, where more organisms can find food.

Bacteria and mycorrhizae have a major interaction in the rhizosphere of the lagimuine group of plants. The interaction between mycorrhizae and N_2-fixing bacteria in the mycorrhizosphere of legume plants significantly affects the mobilization and cycling of nutrients. Also, the interaction between bacteria and mycorrhizae in the rhizosphere significantly affects the lagumuna plant varieties. The positive impacts on host plants may be increased by AMF-associated microbes. It appears likely that AM and other soil microbes may interact in a synergistic or antagonistic manner, depending on the species involved. Due to its widespread cultivation, the majority of study has focused on the AM-Rhizobium-N_2-fixation relationship in legumes.

When compared to nodal roots, wheat seminal roots sustain a higher rhizosphere population of bacteria, actinomycetes, and fungi (Sivasithamparam *et al.*, 1979). These variations were thought to be the result of anatomical variations in the cortical root tissue. Epidermal cells tend to disappear from seminal roots, and some cortical cells close to the root surface have been harmed. The cortical cells found in the nodule roots tended to remain whole, with minimal remaining cell material. Depending on the rhizosphere species and how long it remains in the soil environment, the influence of the roots and rhizosphere vegetation affects the soil structure in both a direct and indirect manner. Direct effect refers to the mechanical action of the root in forming pores and gaps in the aggregates, however, it is generally accepted that indirect effect due to the activity of rhizosphere microorganisms has a higher impact on the soil structure. For ecological soil management, soil structure is crucial.

Rhizosphere pH and Mycorrhiza Relation on Nutrient Uptake

If the secretions drained to the root area are acidic, the pH of the rhizosphere varies up to 2-3 units (Marschner *et al.*, 1986; Ortas *et al.*, 2004). By several methods, soil pH influences and mobilizes the main forms of P (Ortas, 2003). Additionally, mycorrhiza alters the pH of the rhizosphere and the movement of nutrients. Mycorrhizal colonization is also very important for shoot and root growth the maize genotype with the largest shoot-root ratio had the greatest root colonization as well. According to (Ortas, 2022) plants with mycorrhizal inoculation have balanced nutrient intake, they are more abundant and healthier. Healthy plants have higher shoot and root growth (Ortas, 2012b). Numerous plants are well-known crop species that depend on AM (Hamel, 1996).

The seminal roots likely provided additional C to the rhizosphere for microbial proliferation through cell lysis. According to Sbrana *et al.* (2014), AMF symbiosis may cause changes in plant secondary metabolism that will increase the manufacture of phytochemicals with health-promoting qualities. Mycorrhiza also changes the secondary metabolism quantity and quality. AMF also interfere with the phytohormone balance of host plants as bioregulators and mycorrhiza acts as a bioprotector to induce tolerance to soil and environmental stresses.

According to Cheng and Gershenson (2007) study, between 5% and 40% of the carbon fixed by photosynthetic processes is released by the shoot to root area. It has been shown that some organic acids secreted by plant roots, including malic, oxalic, and citric acids, are essential for nutrient uptake in ecological settings. Carbon and nitrogen are converted under that plant exudation condition to energy for soil microbial activity. Additionally, populations on and in the root tissue grew with plant age, whereas the number of bacteria, actinomycetes, and fungi in the rhizosphere declined (Sivasithamparam *et al.*, 1979).

Mineral Nutrient Effects on Soil pH and Mycorrhizae Development Related to Nutrient Uptake and Plant Growth

Many soils have mineral especially phosphorus (P) deficiency issues all over the world, thus organic fertilizer is required for the desired ecological production. Mycorrhizae are a potential organism for absorbing P aside from organic fertilizer. P have a stronger impact on root colonization in P-sufficient soils than in N-deficient soils (Francis *et al.*, 2023) Plant P concentrations were also higher in the ammonium treatment than in the nitrate treatment. According to Ruan *et al.* (2000), treatments with NH_4 considerably increased tea plant leaf dry matter production compared to treatments with NO_3. According to research done by Malagoli *et al.* (2000), some forest tree plants can use ammonium more effectively than nitrate, with an ammonium net absorption rate many times higher. It has already been observed that plants use different forms of N and that this involves not only uptake, but also storage, and incorporation processes. NH_4^+ and NO_3^- are quite different ions in many respects for plant and soil organisms. NH_4^+ is a cation and NO_3^- an anion, so their chemical processes are facilitated by different sets of reactions especially rhizosphere pH changes (Ortas, 1996; Ortas and Rowell, 2000; Ortas *et al.*, 2004). The N2-fixing rhizobia bacteria and mycorrhizae fungi are the most relevant representatives of beneficial plant symbionts (Barea, 2015) which are directly related to nutrient uptake and cycling. The N_2-fixation cycle itself is a separate study, however as the uptake of gaseous N_2 would provide an extra source to plants for their N-nutrition, as well as relieving some pressure on the soil organic N pool, it needs to be re-considered for soil and crop quality.

When no P or soluble P was supplied, the effect of N forms on rhizosphere pH change was considerably greater and reached up to 1.30 units, extending to 3-5 mm away from the root surface (Ruan *et al.*, 2000). Ortas (1994a) compared the effects of mycorrhiza with control treatments and found 0.01 to 0.27 unites changes (Table 2). The effects of N form on pH change are much higher than mycorrhizal inoculation.

Table 2. The effect of ammonium or nitrate on mycorrhizal infection and rhizosphere and non-rhizosphere soil pH of sorghum plants

Soil	AMF	Mycorrhizal infection (%)		Rhizosphere soil pH		Non-rhizosphere soil pH	
		NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-
Soil 1	-M	0.8(0.8)	0.8(0.8)	7.62(.04)	7.76(.04)	7.93(.03)	8.01(.05)
	+M	63.3(14.6)	60.8(9.2)	7.45(.02)	7.93(.01)	7.92(.03)	7.99(.03)
Soil 2	-M	0(0)	1.1(1.1)	5.27(.05)	6.21(.03)	5.89(.03)	6.27(.05)
	+M	56.9(11)	56.5(4.4)	5.10(.01)	6.34(0.2)	5.78(.03)	6.35(.03)

Nitrogen Fixation and Related Mycorrhizae

It seems like the whole microorganism interaction between species and related to root ecosystems situation might be extremely complicated. The Rhizobium-AM-leguminous plant interaction exists and some legumes grew so poorly without mycorrhizas as to be ecologically obligate mycorrhizal. Mycorrhiza species were associated with N_2-fixing microorganisms, it was suspected that N increases were not due to uptake from soil but essentially due to these specialist N_2-fixers. Barea et al. (1989) have recently shown that AM improve symbiotic N_2 fixation, almost certainly through improving plant phosphorus uptake as well. The relationship between AM and other rhizosphere residents, however, is poorly understood (Azcon, 1989). In an experiment involving rhizosphere bacteria and AM, the growth of plants with AM was found to be increased by bacterial inoculation, but this was not always the case some of the mycorrhizal tomato plants used did not respond to bacterial introduction in terms of growth, and in those that did, there was a gradient of effectiveness. According to (Ortas *et al.*, 2004; Barea, 2015), some bacteria from various genera collectively known as "rhizobia" to fix N_2 in mutualistic symbiosis with legume plants, while others (actinomycetes) from the genus Frankia form N_2-fixing nodules on the roots of the so-called "actinorrhizal" plant species. According to Barea and Richardson (2015), some microbes' ability to mobilize phosphorus from scarcely accessible sources can aid in the nutritional uptake of plants. Mycorrhizae improve the supply and availability of nutrients; this effect is a result of the mycorrhizal fungi's stimulatory effect on the biochemical cycle of nutrients. N2-fixers, P-mobilizers, and AM fungi are the primary microorganisms in the rhizosphere and mycorhizosphere that are involved in the cycling of N or P. Because mycorrhizas aid in the development of stable aggregates, they enhance the soil's structure. They defend the plant against biotic and abiotic stressors. The mycorrhizal symbiosis aids in the biological control of diseases and boosts a plant's resilience to adverse environmental conditions such as salt, drought, nutrient deficiencies, excess heavy metals, soil degradation, etc. N-nutrition was affected by mycorrhizas, and (Ortas, 1994b; Ortas *et al.*, 1996; Ortaş and Harris, 1996) showed that nitrogen forms have a significant effect on mycorrhizae rhizosphere dynamics.

Pre-establishment of mycorrhizae improved cowpea nodule activity, and root and shoot dry weight however not show any competitive interaction with Rhizobium for nodulation sites (Ames and Bethlenfalvay, 1987). Pacovsky *et al.* (1986) searched an AM-Azospirillum-sorghum mixture and found that in the presence of Azospirillum, free-living, N2-fixing bacteria, AM colonization of sorghum roots increased.

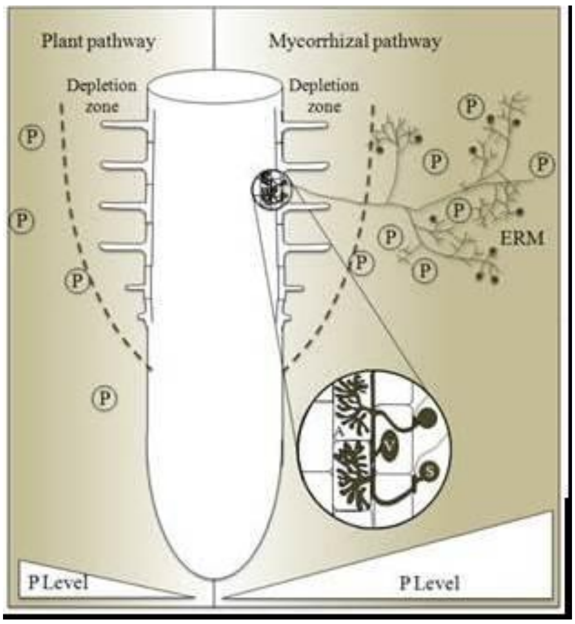
Mycorrhiza is a Powerful Mechanism for Plant Growth

Mycorrhizal inoculated plant root has an extensive hypha, which increases the capacity of absorptive surface area of the plants. Accordingly, the external hyphae take up nutrients from the soil solution and transport them to the root and another part of plant. As mycorrhizal plants are getting more nutrients and water, they are more competitive and better able to tolerate environmental stresses than are non-mycorrhizal plants.

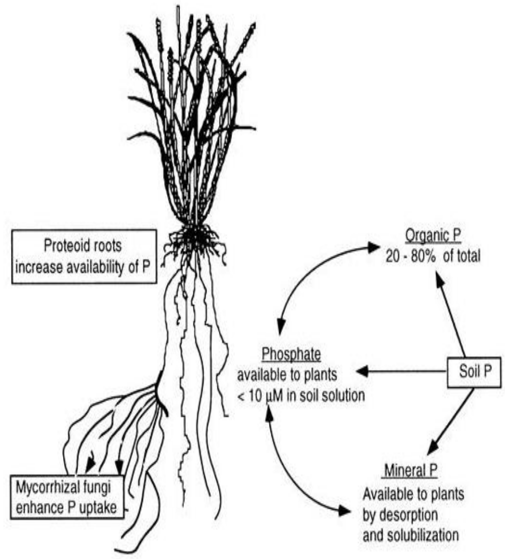
Generally, there are three mechanisms are responsible for enhanced P uptake in mycorrhizal plants. 1) the hyphal network of AM fungi that extends the plant root system, 2) the release of organic acids that solubilize phosphate from insoluble Al-P, Fe-P and Ca-P complexes, and 3) phosphatase enzyme production and exudate to the rhizosphere that accelerates organic P mineralization to inorganic phosphate. Nye and Kirk (1987) data indicate that plant roots is increasing soil P availability in neutral or alkaline soils which decreases the pH at the root-soil interface and thereby mobilizes sparingly soluble calcium phosphates. LI *et al.* (1991b) also indicated similar results.

Some microorganisms may act with mycorrhiza fungi to release immobile forms of P to the soil solution. P is one of the critical minerals for plant growth and makes up about 0.2% of dry weight, but it is one of the most difficult nutrients for plants to acquire (Smith *et al.*, 2011). Phosphorus is involved in several biochemical mechanisms such as the formation of cell membranes, carbohydrate metabolism, protein synthesis, photosynthesis, respiration sugar metabolism, energy storage and transfer. (Schachtman *et al.*, 1998) indicated that since P is a component of key molecules such as nucleic acids, phospholipids, and ATP, and, consequently, plants cannot grow without a reliable supply of this nutrient. Soil P concentration may be large however most of it is not available or less mobile because of the very low solubility of phosphates of iron, ammonium and calcium, leading the soil solution P concentration of 10 μm or less (Schachtman *et al.*, 1998). Phosphorus in soil can be in organic (20 to 80% of P in soils is found in the organic form) and inorganic forms. Most of the organic P is in phytic acid (inositol hexaphosphate) form. According to Holford (1997) the inorganic P fraction contains 170 mineral forms. Since P concentration and availability in the soil solution is low, in the bulk soil plant uptake is also limited. It is well known that 80 % of applied fertilizer P remains in the bulk soil and is less mobile. Consequently, recovery of P is less mobile minerals, which is moved mainly by diffusion. Since the rate of diffusion of P is very slow (10^{-12} to 10^{-15} m^2 s^{-1}), high plant uptake rates create a zone around the root that is depleted of P (Schachtman *et al.*, 1998; Ortas *et al.*, 2004).

Bücking and Kafle (2015) explained the nutrient uptake by root hair and mycorrhizae hyphae (Figure 3). They indicated that “Plant uptake and mycorrhizal uptake pathway.



A Bücking and Kafle (2015)



B:Schachtman et al. (1998)

Figure 3. Plant P uptake mechanisms from the soil.(Schachtman et al., 1998).

Uptake and Transfer of Soil Nutrients through Hyphae

The extraradical hyphae are also important to increase the uptake of ammonium, immobile micronutrients such as Cu and Zn and other soil-derived mineral cations (K^{+}, Ca^{2+}, Mg^{2+}, and Fe^{3+})(Smith and Read, 2008). Some species are more strongly mycorrhizal dependent than others. It has been calculated that extraradical hyphae of mycorrhizas could contribute up to 80% of plant P, 25% of plant N, 10% of plant K, 25% of plant Zn, and 60% of plant Cu uptake (Marschner and Dell, 1994). According to (Liu et al., 2000), mycorrhizal inoculation plants had considerably greater shoot concentrations of P, Mg, Zn, and Cu than non-mycorrhizal plants.

The association of roots with arbuscular mycorrhizal (AM) fungi is a very widespread strategy by which plants facilitate their acquisition of mineral elements from the soil (Marschner, 1995). AM fungi differ in the total amount of external hyphae length is the main power for more nutrient uptake. In addition to element uptake via mycorrhizal mycelia, AMF have also been shown to affect root morphology and functioning, as well as mycorrhizosphere soil properties. This may lead to indirect effects of the AM association on plant nutrient availability and uptake (Smith and Read, 2008). With their thin diameter, AM hyphae might be able to access smaller soil pores, and better compete with soil microbes for nutrient resources, compared with plant roots. Neumann and George (2010a) indicated that like plant root systems, AM hyphae seem to differ considerably in their architecture and physiological activities depending on their genotype (Figure 4). Mycorrhizal hyphae length is also controlled by nutrient level mainly by soil phosphorus levels.

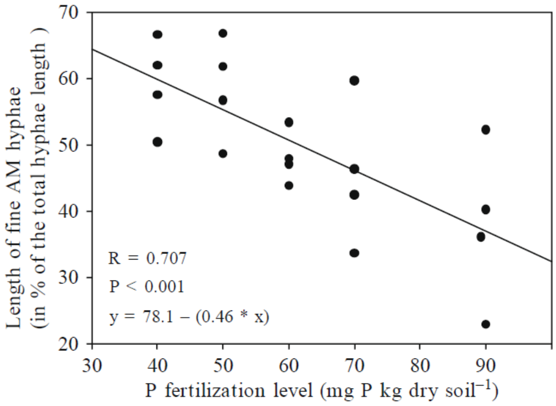


Figure 4. Effects of P level on mycorrhizal hyphae and relation with nutrient uptake (Neumann and George, 2010b).

The external hyphae of AM fungi extend well beyond the depletion zone, accessing supplies of nutrients at a distance and in narrow soil pores. Since the hyphae develop around the root distributed beyond the root area, nutrient uptake is high and the nutrient depletion zone is expended. When nutrients are removed from the soil solution more rapidly a nutrient depletion zone develops and that nutrient can be replaced by diffusion (Li *et al.*, 1997). For a poorly mobile ion such as phosphate and potassium, a sharp and narrow depletion zone develops close to the root. AMF can secrete phosphatases to hydrolyse phosphate from organic P compounds (Koide and Kabir, 2000 and Marschner, 2012), thus improving crop productivity under low input conditions (i.e. phosphorus deficiency, Smith et al., 2011).

Li *et al.* (1991a) reported that in the non-mycorrhizal plants, the depletion of $NaHCO_3$-extractable P extended about 1 cm into the outer compartment, but in the mycorrhizal plants a uniform P depletion zone extended up to 11.7 cm (the length of the hyphal compartment) from the root surface. Also in the same experiment, they found that in the outer compartment, the mycorrhizal hyphae length density was high (2.5–7 m cm^{-3} soil) at the various distances (0–11.7 cm) from the root surface (Li *et al.*, 1991c). The uptake rate of P by mycorrhizal hyphae was in the range of $3.3–4.3\times10^{-15}$ mol s^{-1} cm^{-1}. Douds and Millner (1999) indicated that the extraradical hyphae of the AMF can develop up to 8 cm beyond the root-growing zone and act as extensions of the root system in acquiring nutrients from the soil.

AM mycelia constitute of morphologically different types of hyphae. Relatively coarse and thick-walled hyphae with a diameter between 5 and 20 µm appear to function mainly in nutrient transport and extension of the fungal colony.

Since AM exploits a large volume of soil AM pathway can reduce the impact of Pi depletion in the rhizosphere and so improve plant P nutrition and growth ((Smith *et al.*, 2011)) Fig. 1). The magnitude of plant growth enhancing effects varies with the nutrient status of the soil. At the same time plant, rhizosphere mechanisms such as mycorrhiza help plants to get high quantity of nutrients mainly P.

The extent of the depletion zone makes AM inoculated plant grow better than a non-mycorrhizal plant. This difference depends plant root system, including the numbers and extent of root hairs. In general, when plants have a low root-shoot biomass ratio, slow root growth rates, and/or poor root hair development plant rot demands mycorrhizae symbiosis. If a high amount of total soil P is poorly available plants demand mycorrhizae and in that case mycorrhizae plants uptake more P and grow over non-mycorrhizal plants (Bolan, 1991).

With the current state of soil technology, inoculation is most feasible for transplanted crops and in areas where soil disturbance has greatly reduced the native inoculum potential. Pro-inoculated seedling can benefit from mycorrhiza to penetrate roots and hyphae in soil. Although for citrus seedling changes in the management of the soil-plant system can be sufficient to optimize the mycorrhiza symbiosis, in horticulture the inoculation of seedlings before transplant has given the best results (Ortas, 2012b).

Mycorrhizas Alter Root Architecture System

Lynch (2005)indicated that plant root geometry and morphology are very important for maximizing nutrient uptake because root systems that have higher ratios of surface area to volume will more effectively explore a larger volume of soil. In the case of mycorrhizae, the area is exploited more volume of soil as well. Since plant roots are infected by mycorrhizae which may facilitate nutrient acquisition and reduce the nutrient fertilizer need. Plant root epidermal cells including root hairs (the direct pathway) uptake orthophosphate (Pi) by leads to the lowering of Pi concentrations in the rhizosphere, which is called depletion zones. Usually, Pi depletion replacement does not easily keep pace with uptake (Fig. 1) (Smith *et al.*, 2011). Plant roots and mycorrhiza fungi take up P as negatively charged Pi ions ($H_2PO_4^-$) forms (Smith *et al.*, 2011). indicated that P depletion poses an additional problem because the concentration in plant cells is about 1,000-fold higher than in the soil solution and the cell membrane has an inside-negative electric potential. According to (Bucher, 2007 in this case Pi uptake requires metabolic energy and involves high-affinity transporter proteins in the Pht1 family Fig 1.

Smith and De Smet (2012) postulated that plant roots are involved in several variety of biological processes, such as nutrient uptake, nutrient storage and mechanical support. In general, the root system architecture (RSA) of plants is very dependent on plant species, and soil environments. Soil composition, soil microorganisms, and water and nutrient availability also can't affect soil structural development. Most tree plant species have short and rare root hairs, and such kinds of plant are dependent on AM-colonization. Wu *et al.* (2010) reported that root architectural alteration in AM-colonized citrus plants could increase root functioning to explore more water and nutrients under stress conditions.

Mycorrhizal root system seems to be able to selectively absorb mainly phosphorus, zinc, copper, and NH_4-Nfrom deficient soils (Liu *et al.*, 2003; Ortas, 2012b). When a nutrient is deficient in soil solution, the root parameters such as surface area, length and nutrient exchange capacity controlling the uptake. If the plant is mycorrhizal dependent or infected with mycorrhizae, the hyphae of mycorrhizal fungi can increase the absorbing surface area of the root (Ortas, 2012c). LI *et al.* (1991b) reported that hyphae of AM fungi contributed 70 % (Cambisol) or 80 % (Luvisol) to the total P uptake of mycorrhizal plants. In another work, George *et al.* (1992) reported that mycorrhizal hyphal uptake 49 % of the total phosphate and 35 % of the total nitrogen by mycorrhizal plants. In addition, they indicated that AM-inoculated plant leaves have several folds more P concentration than non-inoculated tree plants. Because of nutrient deficiency, particularly N, P, K, Zn and Fe and low organic matter, high clay and $CaCO_3$ content and high pH, fruit trees grow slowly. Guissou *et al.* (2016) indicated that AM inoculation significantly improved the N, P and K absorption compared to non-AM fruit trees.

Advantages of Mycorrhizal Dependency to Plant

Mycorrhizal dependency (MD) of the host crop is depended on soil fertility and fertilizer levels (Ortas, 2012c; Ortas, 2012a). Plants with coarsely branched roots and with few or no root hairs are expected to be more dependent on mycorrhiza than plants with finely branched root systems (Smith and Read, 2008). Mycorrhizal dependency and mineral nutrition potential have been focused on by many researchers and it has been indicated that the benefits of AM fungi on plant growth could vary widely between plant species, and even between cultivars or species from different geographic locations (Plenchette *et al.*, 2005; Sousa *et al.*, 2013). Nutrient uptake and MD may depend on genetic diversity in tree species as well. It has been found that there is a big difference between plant species in term of mycorrhizal species selection. Moreover, the effectiveness of mycorrhizal inoculation seems to be much more dependent on soil fertility, the effectiveness of spores and a number of spores. Mycorrhiza dependency of plants is depended on soil, plant and inoculum species. The degree of plant dependence is of great practical and ecological interest for plant nutrition. In most cases, plants' P requirements for growth in the soil to control the mycorrhizal dependences. Also, plant species mycorrhizal dependence can vary with available soil P concentration (Hetrick *et al.*, 1996). Nutrient uptake and MD may depend on genetic diversity in tree species as well.

Mycorrhizal dependency cannot be easily predicted either by root colonization measurements nor by root architecture (Guissou *et al.*, 1998). As indicated by several authors (Sorensen *et al.*, 2005; Janos, 2007) the length and the density of root hairs may be a good indicator of plant species or cultivars for MD.

Conclusion

Mycorrhizal fungi, the unsung heroes of soil ecosystems, form crucial partnerships with nearly 80% of terrestrial plants. Plants and symbiotic mycorrhizal fungus have co-evolved mutualistic interactions in which the health and fitness of the former rely on the latter. AMF may be utilized as a substitute for reduced fertilizers since evidence suggests that the organic farming system increases the inoculum levels of AMF with greater crop colonization, which led to enhanced nutrient uptake.

Mycorrhizal associations play a critical role in the interactions between plants and soil, encouraging nutrient uptake, boosting soil structure, and increasing plant resilience. In general, many studies show that the development of AM symbiosis in majority of plant species causes physiological changes that boost growth and production, and increase stress tolerance to both biotic and abiotic factors. Mycorrhizae are also essential for plants to withstand transplant shock from greenhouse to filed conditions.

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