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THE ROLE OF MYCORRHIZAL RELATIONSHIP IN SUSTAINABLE MANNER TOWARDS PLANT GROWTH AND SOIL FERTILITY

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Abstract: *Mycorrhizae are symbiotic associations, formed between plants and soil fungi that play an essential role in plant growth, plant protection and soil fertility. The AM (Arbuscular Mycorrhizae) fungi expand their filaments in soil and plant roots. These filamentous networks promote bi-directional nutrient movement where soil nutrients and water move to the plant and plant photosynthesis flow to the fungal network. AM fungi are ubiquitous in the soil and can form symbiosis with most terrestrial plants including major crops, cereals, vegetables and horticultural plants. Soil microbial populations are immersed in a framework of interactions known to affect the soil quality. AM fungi induced changes in plant physiology; affect the microbial populations both qualitatively and quantitatively, in rhizosphere or mycorhizosphere. Therefore, the rhizosphere of a mycorrhizal plant has different features than those of a non-mycorrhizal plant. AMF involved in fundamental activities that enhanced the productivity of both agricultural and natural ecosystems. Major factors that constrain soil quality and sustainable agriculture are low nutrient availability, moisture stress, soil erosion, fixation of phosphorus, high acidity with aluminium toxicity and low soil microbial biomass, biotic and abiotic factors, etc. Due to their obligate symbiotic status, AM fungi need to associate with plant for growth and proliferation.*
Keyword*: Mycorrhizal, Plant growth, Rhizosphere, and Soil fertility*

Introduction: Arbuscular Mycorrhizal Fungi (AMF) is a group of obligate biotrophs, to the extent that they must develop a close symbiotic association with the roots of a living host plant in order to grow and complete their life cycle [1]. The term "mycorrhiza" literally derives from the Greek mykes and rhiza, meaning fungus and root, respectively. AMF can symbiotically interact with almost all the plants that live on the Earth. They are found in the roots of about 80-90% of plant species (mainly grasses, agricultural crops and herbs) and exchange benefits with their partners, as is typical of all mutual symbiotic relationships [2]. They represent an interface between plants and soil, growing their mycelia both inside and outside the plant roots. AMF provide the plant with water, soil mineral nutrients (mainly phosphorus and nitrogen) and pathogen protection. In exchange, photosynthetic compounds are transferred to the fungus [3].

The mycorrhizal symbiosis is a key stone to the productivity and diversity of natural plant ecosystems [4]. The symbiosis is a highly evolved mutualistic relationship found between fungi and plants, the most prevalent plant symbiosis known [5]; and as a result VAM symbiosis is found in more than 80% of vascular plant families of today [6]. The symbionts are formed by the majority of the vascular flowering plants and are found in ecosystems throughout the world. In general, the symbionts trade nutrients, and the arbuscular mycorrhizal (AM) fungus obtains carbon from the plant while providing the plant with an additional supply of phosphorus (as phosphate). While much research has focused on nutrient exchange, the VAM symbiosis is associated with a range of additional benefits for the plant including the acquisition of other mineral nutrients, such as nitrogen, phosphorus and resistance to a variety of stresses such as drought, soil/root borne pathogens, salts, heavy metals and soil stability.

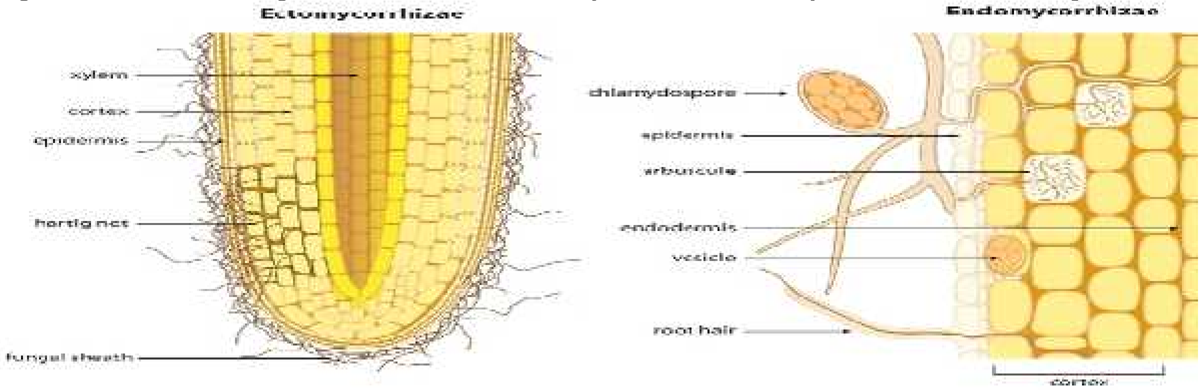
Sustainability refers to productive performance of a system over time. It implies use of natural resources to meet the present needs without peril the future potential. The Technical Advisory Committee of the Consultative Group on International Agricultural Research has defined sustainability as “successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources” Technical Advisory Committee (TAC) [7]. Currently, there isconsiderable resistance against the use of chemical pesticides and fertilizers because of their hazardous influence on the environment, and on soil, plant, animal, and human health. Hence, use of microbial inoculants, including mycorrhizal fungi is recommended in practical agriculture [8]. Thus, mycorrhizal technology becomes an important consideration in low input, organic or soil-less agriculture. The desire to exploit VAM (glomalin protein) as a natural biofertilizers for the agricultural biotechnology industries are understandable, but it became clear that more knowledge is needed of the fungi themselves to allow commercial exploitation. The benefit of the symbiosis for nutrient uptake by plants in agro-ecosystems is important as the knowledge is applicable to human endeavors for ecosystem management, restoration and sustainability. In view of this, more complete understanding of how to manage vesicular Arbuscular mycorrhiza (Glycoprotein) for optimum plant growth, health and development is needed urgently as high-input plant production practices are challenged by a more sustainable biological production approaches.

Soil quality defined as the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintenance or enhance water and air quality, and support human health and habitation. Soil quality and its importance in agricultural sustainability; and environmental ecology have been recognized in recent years [9]. The soil quality, soil health and soil condition are interchangeable. Owing to improper land use and management, soil erosion, acidification, nutrient depletion, pollution etc., affect the soil quality. Therefore, it is urgent need to improve soil quality by maintaining sustainable agricultural land use and management practices. One of the ways to improve the soil properties and quality is through AMF.

Types of Mycorrhizae: Of the many types of mycorrhizal association [10], two are of major economic and ecological importance: ectomycorrhizal associations, and the endomycorrhizal association of the vesicular-arbuscular (VA) type. In ectomycorrhizal associations, the fungi invade the cortical region of the host root without penetrating cortical cells. The main diagnostic features of this type of mycorrhiza are the formation within the root of a hyphal network known as the Hartig net. Mycorrhizal Fungi and Plant Nutrition M. Habtecal cells and a thick layer of hyphal mat on the root surface known as sheath or mantle, which covers feeder roots. Infection of host plants by ectomycorrhizal fungi often leads to changes in feeder roots that are visible to the naked eye. Feeder roots colonized by the fungi are thicker and more branched than uncolonized roots; ectomycorrhizal feeder roots also tend to be colored differently. In endomycorrhizal associations of the VA type, the fungi penetrate the cortical cells and form clusters of finely divided hyphae known as arbuscules in the cortex. They also form vesicles, which are membrane-bound organelles of varying shapes, inside or outside the cortical cells. Arbuscules are believed to be the sites where materials are exchanged between the host plant and the fungi. Vesicles generally serve as storage structures, and when they are old they can serve as reproductive structures. Vesicles and arbuscules, together with large spores, constitute the diagnostic features of the VA mycorrhizas. Roots have to be cleared and stained in specific ways and examined under a microscope to see that they are colonized by VA mycorrhizal fungi.

Functions of mycorrhizal: Results of experiments suggest that AM fungi absorb N, P, K, Ca, S, Cu, and Zn from the soil and translocate them to associated plants [11]. However, the most prominent and consistent nutritional effect of AM fungi is in the improved uptake of immobile nutrients, particularly P, Cu, and Zn [12]. The fungi enhance immobile nutrient uptake by increasing the absorptive surfaces of the root. The supply of immobile nutrients to roots is largely determined by the rate of diffusion. In soils not adequately supplied with nutrients, uptake of nutrients by plants far exceeds the rate at which the nutrients diffuse into the root zone, resulting in a zone around the roots depleted of the nutrients. Mycorrhizal fungi help overcome this problem by extending their external hyphae to areas of soil beyond the depletion zone, thereby exploring a greater volume of the soil than is accessible to the unaided root. Enhanced nutrient uptake by AM fungi is often associated with dramatic increase in dry matter yield, typically amounting to several-fold increases for plant species having high dependency on mycorrhiza. AM fungi may have biochemical capabilities for increasing the supply of available P and other immobile nutrients. These capabilities may involve increases in root phosphatase activity, excretion of chelating agents, and rhizosphere acidification. However, these mechanisms do not appear to explain the very pronounced effect the fungi have on plant growth [13]. AM fungi are often implicated in functions which may or may not be related to enhance nutrient uptake. For example, they have been associated with enhanced chlorophyll levels in leaves and improved plant tolerance of diseases, parasites; water stress, salinity, and heavy metal toxicity [14]. Moreover, there is increasing evidence that hyphal networks of AM fungi contribute significantly to the development of soil aggregates, and hence to soil conservation [15].

Figure-1:Schematic showing the difference between ectomycorrhiza and endomycorrhiza colonization of plant roots.



Impact of AM Fungi on Plant Growth: AM Fungi are known to improve plant growth and health by improving mineral nutrition, or increasing resistance or tolerance to biotic and abiotic stresses [16]. AM fungi help in the modification of soil-plant-water relations, promoting better adaptation of plant to adverse environment conditions (drought, metals). AM fungi maintain stomatal opening and hence carbon gain to lower soil water potential and water content [17]. Increased plant nutrient supply by extending the volume of soil accessible to plants. Increase mobilization and transfer of nutrients (P, N, S, micronutrients such as, Cu and Zn) from the soil to the plant. Increase plant nutrient supply by acquiring nutrient forms that would not normally be available to plants [18]. Root colonisation by AM fungi can provide plant protection from parasitic fungi and nematodes. Mycorrhizal benefits can include greater yield, nutrient accumulation, and/or reproductive success [19]. AM fungi add carbon storage in soil by altering the quality and quantity of soil organic matter [20]. Mycorrhizas can influence the nutritional quality of food by influencing uptake of micronutrients and pollutants [21]. AM fungi Increase production of plant growth hormones such as gibberellins and cytokinins. AM fungi enhance the nutrient use efficiency. AM fungi hyphae extend into the soil, penetrating into nutrient depletion zone and increased the effectiveness of immobile elements by as much as sixty times [22]. AM fungi having the ability to sequester heavy metals through the production of chelates and they accumulated; and immobilized in the mycorrhizal sheath [23]. The hyphae of AM fungi produced Glomalin (glycoprotrien) in the rhizospheric soil, which play a role in the immobilization (filtering) of heavy metals at the soil-hypha interface, i.e. before entry into fungal-plant system.

Impact of AM Fungi in Soil Fertility: During development of AM, the fungal symbionts grow out from the mycorrhizal root to develop a complex, ramifying network into the surrounding soil which can reach up to 30 m of fungal hyphae per gramme of soil [24]. This network can make up to 50% of fungal mycelium in soil [25] thereby representing a major part of the soil microbial biomass [26]. This mycelial network can have a binding action on the soil and improve soil structure. In addition, the secretion by AM fungi of hydrophobic, ‘sticky’ proteinaceous substances, referred to as glomalin [25], also contributes to soil stability and water retention [27]. The combination of an extensive hyphal network and the secretion of glomalinare considered to be an important element in helping to stabilise soil aggregates, thereby leading to increased soil structural stability and quality [27]. Agronomic practices such as monoculture cropping, ploughing, or fertilisation have frequently been observed to have a negative impact on the amount as well as the diversity of AM fungi present in soils [28]. A reduction in fungal biomass will result in a negative effect on soil stability and consequently increase the risk of soil erosion. This is not to be underestimated; in the UK, productivity loss due to soil erosion of agricultural soils has been estimated to 9.99 million €/year [29].

Impact of AM fungi on Soil Physical Quality: Formation and maintenance of soil structure will be influenced by soil properties, root architecture and management practices. The contribution of microbial co-operation in the rhizosphere to the formation and stabilization of soil aggregates has been demonstrated frequently [30]. Mycorrhizal fungi contribute to soil structure by

- Growth of external AMF hyphae into the soil to create a skeletal structure that holds soil particles.
- AMF help in an enhancement of microaggregates by external hyphae and roots to form macro aggregates.
- AMF with other microbes play a vital role in the formation of water-stable soil aggregates in different ecological situations [31].
- The hyphae of AMF also play an important role in stabilization of soil aggregates [24].
- The soil fungal mycelium entangles soil particles within the hyphae network and cement or fortify the soil particles together through exudation of extracellular polysaccharide compounds e.g. Glomalin [32].
- AMF can alleviate the desertification [4].

Impact of AM fungi on Soil Chemical Quality: The major role of AMF is to supply phosphorus to the plant because it is an immobile nutrient element in soils. Even if phosphorus was added to soil in soluble form soon, it becomes immobilized as organic phosphorus or fixed in soil colloid as calcium phosphates or iron and aluminum phosphate. AM fungi are known to be effective in increasing nutrient uptake, particularly phosphorus in low phosphorus soil [19]. Under drought conditions the uptake of highly mobile nutrients such as NO3 - can also be enhanced by mycorrhizal associations [33]. It directly taps carbon resources of the plant to the soils [30]. AMF release organic acids and phosphatase enzymes. The mycorrhizal hyphae extend root surface area and exploring larger soil volume, which will increase the chances of more micronutrient uptake. At low phosphorus-levels in soil, mycorrhizae substantially increase copper and zinc contents of the shoot. AMF increase the supply and uptake of N, P, K, Zn, Cu, S, Fe, Ca, Mg and Mn to the roots of host plants; and hence enhanced the plant and soil quality [9].

Impact of AM fungi on Soil Biological Quality: Arbuscular mycorrhizal fungi associations have been shown to reduce damage caused by soil-borne plant pathogens. Biological control of plant disease is the suppression of disease symptoms and disease incidence by the application of a biological agent, usually a microorganism (mycorrhiza). It is a safe and environmentally acceptable alternative for control plant diseases. AMF modify the quality and abundance of rhizosphere microflora and influence soil microbial. AMF can act as biofertilizers, bioprotectants, or biodegraders [34]. Mycorrhizal fungi function as effective suppressors of pathogenic soil borne fungi [35] and plant parasitic nematodes [36] through competiton for nutrients and space on the root against the pathogenic soil borne fungi and also produce antibiotic substances that inhibit the fungal pathogens.Prior colonization, mycorrhizal fungi may also stimulate the root to produce natural defensive wall structures and chemicals (chitinases and phytoalexins) that protect the root from attack by pathogens. Hyphae are conduits that may transport carbon from plant roots to other soil organisms involved in nutrient cycling processes. AMF continuously supply organic carbon or carbohydrates to the soil microorganisms, while it can produce compounds that increase root cell permeability, thereby increasing the rates of root exudation and stimulates the growth of AMF hyphae in the rhizosphere. Rhizosphere microorganisms produced biologically active substances (e.g. amino acids, plant hormones, vitamins, other organic compounds and volatile substances) that stimulate the growth rates of AMF [37]. AM fungi often comprise the largest portion of the soil microbial biomass [38].

Conclusion: AM fungi may enhance the survival of plants in polluted areas by better nutrient acquisition, water relations, pathogenic resistance, production of phytohormone, soil aggregation formation, amelioration of soil structure and thus overall improved soil quality.

Especially, AM fungi are very useful in agriculture because it serves as a biofertilizer as it helps in the absorption of phosphorus, and other nutrients.

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