ISSN: 2977-4047

Journal of Life Sciences Research and Reviews

SCIENTIFIC Research and Community

Review Article

Open Access

Arbuscular Mycorrhizal Fungi Advantageous Impact on Sustainable Agroecosystems and Bridge between Plants, Soils, and Humans Health

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ABSTRACT

Malnutrition is a worldwide problem that has a negative impact on the physical health, development, and ability to recover of children. Protein-calorie malnutrition (PCM) is prevalent in pregnant women, the elderly, and small children and is a primary cause of obesity in developing nations. Vitamin A, iron, iodine, zinc, and folate are necessary for maintaining a well-rounded diet and promoting optimal nutrition. Approximately 33% of individuals in sub-Saharan Africa do not have access to these essential nutrients, which has a detrimental impact on their mental and physical well-being, energy levels, and economic development. Oral microbial communities, such as Streptococcus and Enterococcus, have an impact on human health and the development of diseases. Malnutrition heightens the susceptibility to infection and death, particularly in infants under the age of five, with diarrhoea and respiratory diseases being the primary contributors to mortality. Gaining a more profound comprehension of the oral microbiota can facilitate the development of more effective management strategies. Children with comorbidities who experience severe malnutrition face a fourfold increase in their chance of mortality. It is crucial for medical practitioners to give priority to the diagnosis and treatment of severe acute malnutrition in children, as the presence of comorbidities raises the risk of death for highly malnourished children by a factor of four.

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Received: May 07, 2024; **Accepted:** May 15, 2024; **Published:** May 27, 2024

Keywords: Mycorrhiza, Microbes, Nutrient Limitation, Human Needs, Soil Health, Sustainable Agro-Ecosystem

Introduction

In the world of sustainable agriculture, mycorrhizal fungi are small but powerful allies. These fungi play an important role in improving soil health, improving soil structure, and increasing nutrients absorption. Mycorrhizal fungi are a type of beneficial fungi that live symbiotically with most plants. The word "mycorrhiza" literally means "fungi root". " These fungi attach to plant roots and form fine filamentous networks (often called mycorrhizal networks) in the soil. Mycorrhizal symbiosis occurs between the roots of more than 90% of all plant species, including some of the most important crop plants, and specialized soil fungi [1-3]. AM fungi establish direct connections not only between roots and soil, but also between root systems of different plant individuals of the same or different plant species [2-8]. AM fungi have several direct effects on plants. Nutrient uptake, pollutant immobilization/detoxification, plant carbon redistribution, induction of resistance to pathogens, signal transduction, stimulation of photosynthesis, drought tolerance, soil physical and microbial regulatory effects on plants, etc. Improving indirect effects for the growth, Yield, and crop quality, multitrophic interaction networks and soil quality [2-4, 9-14]. In addition to fine-tuned molecular interactions with host plants, fungi also interact with soil microbes and perform important ecosystem functions such as mineralization of organic nutrients and stabilization of soil organic matter, and these interactions are further modulated by environmental conditions (soil, climate, ecosystem management) [15-20]. The purpose of this manuscript is to describe the function of AM fungal symbiosis in natural and anthropogenic systems, to promote and establish a mechanistic understanding of the formation, extent and dynamics of AM fungal hyphal networks and associated microbes in soil, to contribute to the increasing knowledge and feedback between human activities and ecosystem function. We focus on the critical role of AM fungal symbiosis across different plant species, soil types, and climate regions.

AM fungi Benefits of utilizing them to Agroecosystems

Meanwhile agriculture was introduced more than 10 million years ago, the world's human population has relied on agriculture for food production. The development of new agricultural techniques and innovations has continuously increased crop yields in proportion to the human population. Specifically, the "Green revolution" of the late 20th century took advantage of technological advances such as breeding high-yielding plant varieties and the development of pesticides and chemical fertilizers to increase crop yields to meet global demand. Yields now appear to have plateaued, and farmland has been severely affected by decades of intensive farming practices. For example, mineral fertilizers not only require huge amounts of energy to production, but raw material resources are also often limited, and their widespread use causes environmental problems such as eutrophication of rivers. Repeated machining and turning of soil, another common practice in modern agriculture, can disrupt soil structure, impede soil water-holding capacity, reduce carbon storage, and lead to runoff and this further affects soil erosion and ultimately the soil's ability to support life. Fungi are important for biodiversity and are central players in soil function. One group of soil fungi that may be affected by modern agricultural practices is arbuscular mycorrhizal fungi (AM fungi). AM fungi form a symbiotic relationship called mycorrhiza with the roots of most plant species. They are primarily composed of thin thread-like filaments called hyphae that penetrate the plant roots and finally penetrate the cell walls. In root cells, AM fungal hyphae form highly branched tree-like structures called arbuscules, which facilitate nutrient exchange between the fungus and the plant host. The hyphae of AM fungi spread outward from the roots of the host plant, absorbing soil nutrients and passing them on to the host. In return, fungi receive carbon-based molecules from plants that are fixed through photosynthesis.

Plant Responses to AM Fungi Dependent

The nutritional mutualism underlying plant-AM fungal symbiosis suggests that their application provides a promising approach to improve plant nutrition. Many laboratory and field studies have demonstrated the potential benefits of AM fungi on soil function and crop yield. The hyphae of AM fungi grow beyond the nutrient-depleted areas of the roots and are much thinner than plant roots, allowing them to access soil pores containing essential plant nutrients that are otherwise inaccessible to the host. Harnessing this ability of AM fungi has the potential to reduce dependence on synthetic fertilizers. In addition to their nutritional role, AM fungi also help plant hosts cope with biotic and abiotic stress factors. Studies on many crops, such as tomatoes, sugarcane, potatoes etc., have shown that plants colonized by AM fungi have better resistance and resistance to pests and pathogens. Plant defense signals may also be transmitted underground through mycorrhizal networks and 'warn' neighboring plants of pests, but the mechanisms remain unclear and studies demonstrating their importance at field scale are lacking and insufficient. AM fungi also increases host plant tolerance to drought and help sustain growth in contaminated soils such as heavy metals. Despite the great potential to exploit crop-AM fungal symbiosis to sustainably increase food production, results are highly variable and depend on environmental factors, plant and AM fungal species involved, and even tends to depend on genotype. Crops such as potatoes appear to have a more consistent AM fungus-mediated growth response than wheat and other cereal grains. The latter lack of responsiveness may be partially due to selective breeding of cultivars for yield-related traits, which are often contrasted with susceptibility or responsiveness to AM fungi. The ability of AM fungi to mediate growth responses is also often compromised by conventional agricultural practices such as tillage, which can sever fungal hyphae and limit AM fungal function. There is evidence that tillage also affects mycorrhizal community structure. However, even after the disruption has stopped, communities may be able to recover quickly. Other pressures that can reduce the diversity and function of mycorrhizal fungi include the use of fertilizers and crop rotation with plants that do not normally support his AM fungi. Fertilizer application is generally considered to have a greater impact on the structure of AM fungal communities than tillage alone, but its effects on plant growth performance have not been well studied. Finally, AM fungal diversity may be promoted in fields where different crop species from different functional groups (annual/perennial, legume/Poaceae) are present. However, the exact relationship of this increase in AM fungal diversity to agricultural productivity remains unclear. AM fungi may increase the stability of grassland plant productivity over time and thus may play a greater role in projected future climate change.

Commercial AM Fungal Inoculants Need Improvement

AM fungi occur naturally in most soils, but to increase the density of AM fungi, farmers often use commercial products consisting of a carrier medium mixed with viable spores infected root bits and fungal hyphae. Inoculation methods vary, but generally these products are applied to the field before sowing or in combination with seed or soil, and theoretically help colonize the roots of the crop, at least during the early stages of growth and development and thus, maximizing profits over time. This is a simple and attractive method, especially as the prices of artificial fertilizers is increasing due to worsening raw material shortages and rising energy prices. With the increasing demand, the supply of such microbial inoculants is also increasing, and its global market value is expected to reach up to USD 11.45 billion by 2026. Some products contain a single AM fungal species, while others use a mixture, with about 20% of other beneficial microorganisms such as nitrogen-fixing bacteria. Given the diversity of products available, it is important that AM fungal inocula are not considered a "one-size-fits-all" solution for improving crop yields [21, 22]. When treated with AM fungi containing inoculants, increases in plant productivity were often somewhat disappointing compared to the expectations obtained in greenhouse and laboratory experiments. In laboratory experiments, environmental factors are tightly regulated, whereas in agricultural settings, dynamic microbial communities and soil nutrient content are thought to determine the differences in benefits observed in field and laboratory experiments. To fill this gap, researchers have found that applying commercially available inoculants often does not improve mycorrhizal colonization of host plants or increase plant productivity. Whether or not a microbial inoculant colonizes a crop depends on the crop type, the indigenous microbial community, the soil type, and whether the soil contains excess amounts that can be taken up by fertilizers. There is growing evidence to suggest that use should be considered on a case-by-case basis. Further field trials are needed to better understand the factors that consistently prevent positive plant responses to AM fungal inoculums and to enable farmers to determine whether the inoculants are suitable for their systems. Another factor contributing to the poor performance of AM fungi in agriculture is the quality of commercially available inoculants, which has recently come under scrutiny. Our study found that of 35 products tested, only 20% of them properly colonized plants, and 35% contained no viable propagules at all. In response to these reports, with the aim of ensuring that microbial products contain viable propagules, are free of pathogens, and are packaged with labels that clearly state their contents and nutritional additives. An expanded list of authors provided a quality and regulatory framework. Improved quality control measures will make the benefits of introducing AM fungi into agricultural soils more predictable, making their application a more reliable and less environmentally harmful method of increasing crop productivity [2-3, 23]. Furthermore, greater scrutiny of the production and use of mycorrhizal inoculants will allow for a more accurate assessment of the sustainability of commercially available inoculants. This is currently unknown as many manufacturers are reluctant to reveal the exact components of their products.

Advantages of Managing Agricultural Systems for AM Fungi

The context-dependence of host plant benefits derived from AM fungi and the inconsistency of many commercial inoculants raise questions about the importance of agricultural soil management to promote AM fungi. However, managing soils for AM fungi has a variety of non-plant benefits, as mycorrhizal fungi contribute to many ecosystem functions, especially relevant to agricultural systems. These include improving soil structure, promoting flocculation, and increasing nutrient cycling. The hyphae of AM fungi secrete ”glomalin”. This is a generic term for a combination of unidentified glycoproteins that bind soil particles to form aggregates, which can increase soil fertility and water-holding capacity, ultimately benefiting crops. Furthermore, practices such as intercropping and conservation agriculture that fall under the category of “sustainable agriculture” not only help conserve below-ground biodiversity, including mycorrhizal fungi, but also often reduce carbon sequestration, pesticides, etc. It also brings related benefits, such as reduced dependence on fertilizer, increasing water storage capacity, improving soil structure, and thus storing nutrients. It is also important to remember that in addition to yield quantity, yield quality is also an important factor to consider in food production. AM fungi have been shown to enhance the biofortification of grains and may also improve crop shelf life. Additionally, more nutritious crops require less and can be achieved by using less fertilizer, making the entire process more efficient, environmentally friendly, and economical. More sustainable management of agroecosystems also leads to a positive feedback loop in which soil conditions and crop varieties become more suitable for mycorrhizal fungi, making these fungi increasingly beneficial to plants. Rather than trying to integrate AM fungi into food production systems, which are generally considered unsustainable, agricultural systems should better integrate broader ecological processes and integrate beneficial soil organisms such as AM fungi.

Outstanding prospects include the establishment and functioning of AM-fungal symbiosis in sustainable agroecosystems. Various literatures indicate that AM fungi play an important role and are beneficial to plants. This is understood by considering the multistep selection that leads to local adaptation. Additionally, some article demonstrated through a meta-analytical approach that specific root respiration (SRR), considered an indicator of mycorrhizal costs, differs between AM and non-mycorrhizal (NM) plants exposed to different nitrogen. In contrast to ectomycorrhizal (ECM) plants. These results add an insightful comparison between two different types of mycorrhizal symbiosis across a gradient of environmental stoichiometry. The literature suggests that compared to shrub plants associated with ECM fungi, shrub plants associated with AM fungi have higher nitrogen concentrations and opposite trends in phosphorus concentrations are observed, such as it has been suggested that under C-limiting conditions and Nitrogen requirements are reduced in shrub plants. AM fungi promote plant growth, especially when nitrogen availability is high. Therefore, it depended on the variation in C sink limitation among plant species. Nevertheless, this result suggests that the management of AM fungal activity (native AM also provide indirect evidence that fungal inoculation or preservation) should not be overlooked. Prasad suggested the possible impact of soil microplastic pollution on AM fungi, which is one of the understudied drivers of global change [8]. After reviewing the current state of knowledge, they outline priorities for future experimental research focused on understanding the importance of emerging filaments such as microplastics for the functioning of ecosystems in general and the AM symbiosis in particular. Other articles included in this collection cover a wealth of aspects related to mycorrhizal function in different agroecosystems and environmental settings. Various studies have shown that crop genotype (plant nutritional and/or compositions (plant mixtures) to achieve different mycorrhizal benefits in terms of plant growth and coexistence with plants and weeds [2, 3, 6, 13, 24-28]. Similarly, some literature describes various abiotic (The benefits of mycorrhizal fungi and their underlying metabolic pathways in banana seedlings exposed to salinity) and biotic (pathogen) stress have been demonstrated. Similarly, the benefits of mycorrhizae in the medicinal plant Eclipta prostrata have also been studied. Therefore, our results generally support previous findings on the ability of AM fungi to regulate the secondary metabolism of a range of medicinal and other plants, despite remaining uncertainties about the influence of mycorrhizae on the composition of volatile compounds [29-31].Thus, most studies aimed to elucidate the physiological mechanisms of abiotic stress responses in AM plants. All studies contributed to the debate on expanding the use of mycorrhizal symbiosis in agriculture and forestry, either as a planned intervention or as a collateral effect.

Future Perspectives

The interactions between plants and AM fungi are complex and have evolved unique properties over more than 500 million years. It is very difficult to decipher the effects of AM fungi on agroecosystems. While insights from laboratory, greenhouse, and field experiments that focus on individual aspects of symbiosis are valuable, agricultural systems are complex and subject to multitrophic interactions and environmental and economic pressures that require careful consideration. Crop yields are important for the economy and food security, but they should not be prioritized at the expense of the long-term productivity of agricultural systems. Although the evidence for mycorrhizal-mediated plant growth responses may be inconclusive, the impact of mycorrhizal fungi on the overall performance and resilience of soil ecosystems should always be considered. The convention on biological diversity, which should specifically include below-ground biodiversity and AM fungi, despite having been ignored for decades. Overall, the ability of crops to form associations with AM fungi appears to vary depending on plant species and environmental conditions. Modern plant varieties and cultivation were more beneficial to AM fungi. More broadly, breeding efforts are being undertaken to ensure the suitability and functionality of crop-AM-fungi associations, particularly under changing climate conditions in the future. The availability of suitable and reliable commercially available inoculants are critical for farmers seeking to transform their farming systems to have less negative impact on the environment. Practices such as reduced tillage, use of cover crops, and elimination of chemical fertilizers are not limited to promoting AM fungi but are increasingly being used to sustainably increase food production due to the other benefits they bring.

Conflict of Interest: The author declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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