Chapter 12

The Role of Mycorrhizal Fungi in Promoting the Sustainable Agriculture

Pooja Narang*, Km Meenu, Desh Deepak and Sameer Chandra

Department of Botany, School of Sciences, IFTM University, Moradabad, U.P., India

*Corresponding author: pooja.narang@iftmuniversity.ac.in

Abstract

Mycorrhizal fungi are not present in any of the more than 80 disease biocontrol solutions currently available on the market. This absence highlights a significant gap in the biocontrol landscape, as these fungi play a crucial role in enhancing plant health and resilience. Future research may reveal innovative ways to integrate mycorrhizal fungi into existing solutions to improve their efficacy against various plant diseases. This neglect is in spite of a wealth of research showing that ectomycorrhizal and arbuscular mycorrhizal fungi are both capable of controlling a variety of plant diseases.Plant diseases caused by Phytophthora, Rhizoctonia, Pythium, Aphanomyces, Verticillium, Fusarium, Macrophomina, and other soil-borne diseases are significantly reduced by mycorrhizal fungi, which are symbiotic fungi that are abundant in the roots and soils of agricultural crop plants. Ecologists and phytopathologists are becoming more interested in using mycorrhizal fungi as a biocontrol strategy to combat soil-borne infections. By fighting plant pathogens for resources, producing antibiotics, inducing hydrolytic enzymes, improving the PR protein, inducing phytoalexins, and stimulating defence-related enzymes, mycorrhizal fungal colonization of roots lessens the severity of disease. This innovative approach not only enhances plant health but also promotes sustainable agricultural practices. As research continues to uncover the mechanisms behind these benefits, the potential for mycorrhizal fungi to transform crop management strategies becomes increasingly promising.

Keywords: Mycorrhizal Fungi, Fungi, Plant diseases, Ectomycorrhizal, Endomycorrhiza

1. Introduction

Mycorrhizae are a type of fungus that have mutualistic interactions with more than 80% of plants on Earth. Frank (1885) was the first to use the name mycorrhiza, which is derived from the Greek words "mukes" (fungus) and "rhiza" (root). These fungi enhance nutrient absorption for plants, particularly phosphorus, while receiving carbohydrates in return. This symbiotic relationship is crucial for plant health and soil ecology, contributing significantly to agricultural productivity. The primary function of mycorrhiza is to establish a connection with plant roots. Glomerales, Diversisporales, Archaeosporales, and Paraglomerales are among the ten families that comprise the four orders of Mycorrhiza (Morin E. et al. 2019). The two main categories of mycorrhiza were ectomycorrhiza and endomycorrhiza. The most common association among these is that of endomycorrhiza, or AMF. According to Harley J. L. et al. (1983), the AMF primarily colonizes the root cortical region of the plant and produces an extramatrical mycelium that is laterally utilized for the acquisition of mineral nutrients, primarily phosphorus, from the soil. This symbiotic relationship enhances the plant's nutrient uptake efficiency, leading to improved growth and resilience against environmental stresses. Additionally, the presence of AMF can influence the overall soil health by fostering a diverse microbial community. This diversity not only supports plant health but also contributes to soil structure and fertility, creating a more sustainable ecosystem. As such, the role of AMF extends beyond individual plants, playing a crucial part in maintaining the balance and productivity of agricultural systems. Ensuring food sovereignty is a serious and challenging problem for humanity. By 2023, there were 7.9 billion people on the planet, and by 2050, that number is predicted to rise to 9.7 billion (United Nations, 2019). Food and other resources must become more readily available as a result of this increase in population density. Furthermore, since more extreme events like heat and cold waves, droughts, and torrential rains are projected, climate change and global warming may be exacerbating factors in this situation (Cramer et al., 2022). Water scarcity, soil erosion, or even the disturbance of the biosphere can result from these occurrences. Crops may be at risk if, for instance, the distribution patterns of some pests, which serve as carriers of plant diseases, are changed (Shipley et al., 2020). In order to address all of these problems, the agricultural sector must boost output while preserving the planet's carrying capacity and avoiding overuse of soils and water resources (Gerten et al., 2020). The indiscriminate use of agrochemicals (mostly fertilizers and insecticides) contributed to the significant growth in global productivity during the green revolution. Although it was a huge breakthrough in those decades, it has now resulted in some very serious problems. It is essential that we change how we use agrochemicals. It is obvious that alternative fertilization techniques must be created because the application rate is usually higher than optimal, resulting in an excess of fertilizer that contaminates the soil and water (Ullah et al., 2019). For example, abuse of fertilizers high in phosphorus and nitrogen can result in an accumulation of these elements, which can be harmful to both humans and animals. For this reason, efforts are being made to boost nitrogen use efficiency (NUE) (Mandal et al., 2020). Additionally, it is believed that fertilizer leakage from the soil is a global phenomenon that results in eutrophication and the death of aquatic organisms (Khanna and Gupta, 2018). Additionally, people's health is negatively impacted by nitrate in drinking water (Kotopoulou et al., 2021). A mineral nutrient imbalance in the soil may have a detrimental effect on the edaphic microbiota. Changes in the microbiome can affect the nitrogen cycle and ultimately agricultural productivity (Mandal et al., 2020). However, pesticides contaminate the soil and water, causing a range of problems that affect human health and the ecosystem because some heavy metals have been created as residues and have accumulated in the food chain (Parrón et al., 2014). As a result, the agricultural sector has to transition to more contextually aware and sustainable solutions. Specific bacteria that impact the target organisms without endangering other beneficial organisms like insects or plant-symbiotic microbes must be the foundation of new biocontrol techniques. In a similar vein, biostimulants must precisely augment the required nutrients while avoiding excesses that could be hazardous or destructive to the environment (Mandal et al., 2020). The use of microbial bioinoculants—products made with the strains of interest of one or more microorganisms—is one suggestion to try to lessen the use of agrochemicals. Bacteria or fungi that produce phytohormones, improve nutrient absorption, mobilize or solubilize nutrients, or create tolerance to abiotic stresses are examples of microorganisms that can stimulate the immune system against diseases and pests (Chaudhary et al., 2020). Bioinoculants can be utilized to enhance the physicochemical characteristics of the soil, decontaminate or detoxify the soil, and enhance plant performance (Maitra et al., 2022). Microorganisms must be part of a homogeneous matrix (carrier) that enables their storage, transportation, and protection in order to perform their job. A carrier that enables the intended objective to be achieved without causing environmental pollution would be excellent. Among the various kinds of carriers are solid, liquid, metabolite, and polymeric formulations. In addition to being non-toxic, sterilizable, and able to accommodate various bacteria, the optimal material should supply the required nutrients (Chaudhary et al., 2020). Mycorrhizal fungi (MF) have a well-established advantage in agriculture, whether they are used alone (Benami et al., 2020; Ejersa, 2021) or in combination with other microorganisms (Yadav et al., 2020; Santoyo et al., 2021).

2. Types of Mycorrhizae

While members of the latter group enter plant cells where direct metabolic exchanges can take place, members of the former group only grow on the outside of root cells. Of the seven different kinds of mycorrhizae, ectomycorrhizae and endomycorrhizae are the most common and numerous (Figure 1). While endomycorrhizal fungus inhabit trees, shrubs, and the majority of herbaceous plants, ectomycorrhizae are primarily found on trees and create visible structures.

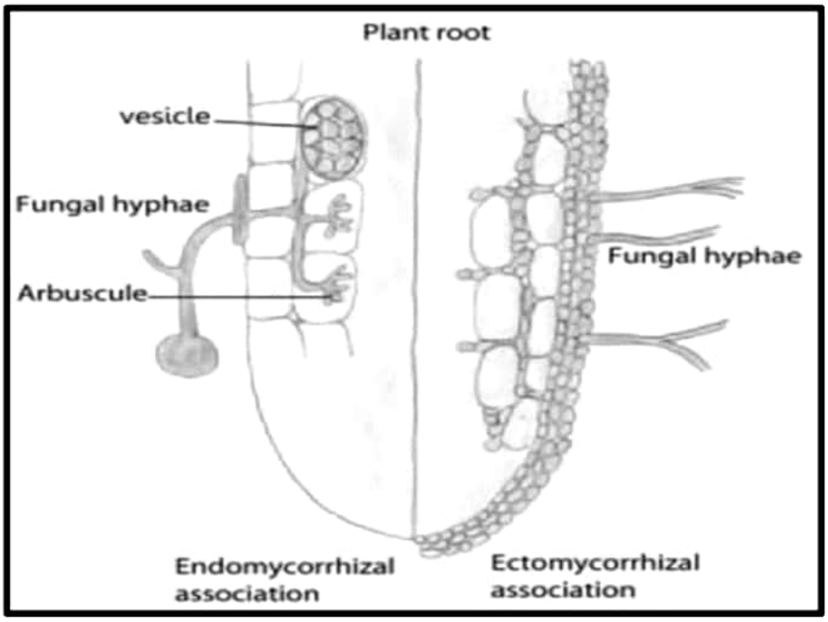

Figure 1. Schematic representation of Endo and Ectomycorrhizal association between plant and fungus Source: Johanson et al., (2016)

(i) Ectomycorrhizae: The hyphae of ectomycorrhizal fungus cannot enter root cells. Around the root tip, the hyphae create a sheath known as the mantle. A Hartig net of hyphae is formed by the mantle's hyphae growing between root cells; occasionally, they can even enter root cells. These fungi are members of the Basidiomycetes, Ascomycetes, and Pycomycetes groups, which have fruiting bodies above ground. Additionally, ectomycorrhizal fungi can be found in natural settings, primarily in forest habitats. When these fungi invade trees, they can produce visible reproductive structures called mushrooms near the base of the tree. Without entering the root cells, ectomycorrhizal fungi grow in between them. A fungal mantle is a dense growth formed by the proliferation of their hyphae on the outside. Five to seven percent of plants are symbiotic with these fungi, which coexist with the majority of pines, spruces, and some hardwood trees like beech, birch, oak, and willow.

(ii)**Endomycorrhizae:** The most prevalent symbiosis, endomycorrhizae, is found on agricultural land and is linked to about 85% of plants. Unlike ectomycorrhiza, these do not alter the shape of the roots, making them more difficult to spot at first glance. Endomycorrhizae come in three varieties: Ericoid, Orchid, and Arbuscular.

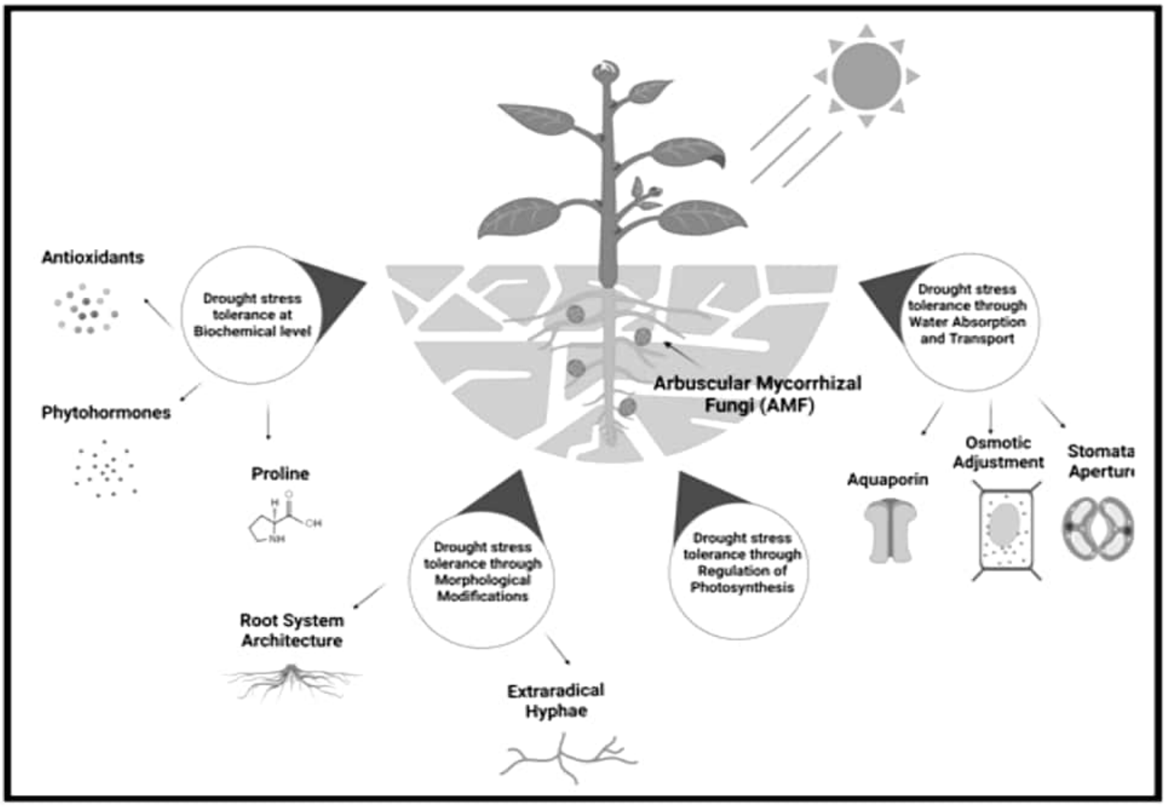

Figure 2. Mechanism of Abuscular mycorhiza in drought stress tolerance (Sources: Das and Sarkar 2024)

Arbuscular mycorrhizal (AM) fungi are the most common type of endomycorrhizal fungus found in soils. Arbuscular mycorrhizae (AM) are the most significant members of the endomycorrhiza group (Figure 2). Since fungal hyphae really pierce the cortical root cell wall and create tiny hyphae-branched structures known as arbuscules once inside the plant cell, the term "vesicular arbuscular mycorrhizae" (VAM) was reduced to "AM." Aseptet hyphae are found in endomycorrhizal fungi, which belong to the Phycomycetes and Basidiomycetes. These fungi's hyphae create an internal hyphae network by penetrating the root cortex's cells. Additionally, some hyphae reach into the ground. Vesicular arbuscular mycorrhizae (VAM) are the most common type of fungal infection for a wide variety of plant species, including the majority of agricultural crops. The existence of two different kinds of structures is the source of this name. Features of the fungi that belong to the Endogonaceae family include vesicles, which are sac-like structures that emerge from hyphae and act as lipid storage organs, and arbuscules, which are finely branched structures that form within a cell and serve as a major metabolic exchange site between the plant and the fungus. These structures are created by dichotomous branching of hyphae and resemble haustoria. The most prevalent and pervasive category are the AM fungus. Eighty percent of plants are associated with endomycorrhizae.

Table 1. Different phases in the life Stage of Mycorrhizal fungi and corresponding aspects of plant –fungus association

Stage	Vesicular-arbuscular mycorrhizal fungi	Ectomycorrhizal fungi	Other Mycorrhizal fungi
Free -living	– Host plant is necessary for long-term survival. – The ability of soil hyphae to survive independently in soil is limited.	– The majority's ability to survive and proliferate without hosts is restricted. – Some are capable of saprotrophic behaviour.	– Prolonged independent stages with other plants as parasites, saprotrophs, or mycorrhizas
Endophytic	– Long-term persistence in the host plants' older roots Hyphae in rhizome scales, non-host roots, etc.	– Partial bond with plants that are not hosts	– Colonisation of bryophytes by ericoid mycorrhizal fungi? – Other plants' orchid fungi
Balanced mycorrhiza	– A typical correlation with arbuscular Many hosts' root growth and structure are optimized for the production of mycorrhiza.	– Hyphae restricted to specific cells – Slow, short root growth to permit fungal colonization – Compatibility with a Harting net	– Mycorrhizas of green orchids? – Ericoid mycorrhizas are considered to be balanced
Exploitive mycorrhiza	– Myco-heterotrophic vesicular-arbuscular plants	– Mynotropa and other myco-heterotrophic plant relationships	– Myco- heterotrophic orchids
Antagonistic	– Non-host plant roots may sustain damage – Host roots may develop defensive compounds and enzymes.	– Host defensive responses and chemical buildup (such as tannin) Incompatible hosts' roots partially colonized – Alterations in hyphal mat soil characteristics that are harmful to other plants	– Pathogens of other plants or fungi are examples of orchid fungus.
Necrotrophic	– Do plants digest arbuscular? – Fungi that transfer nutrients from senescent roots	– Hyphae may invade senescent root cells – Nutrients may be transferred to other hosts.	– Digestion of hyphal coils by plants? – Fungi that are incompatible and destroy orchids

3. Importance of Mycorhiza in Sustainable Agriculture

The majority of terrestrial plants are associated with mycorrhizae, one of the most common forms of soil microbes, to improve their establishment, growth, and survival. Gaining insight into the mechanics underlying their operation may lead to increased agricultural yield, especially under stressed conditions. Study up on mycorrhizal interactions and how they improve crop growth and yield. "Mycorrhizae," which means "fungus-root," refers to the symbiotic or mutually beneficial association that goes on between soil fungi and plant roots. Nearly 90% of land plants form mycorrhizal relationships for growth and development, and mycorrhizal fungi are common. 250 000 plant species and over 50,000 fungus species create mycorrhizal connections. Angiosperms, gymnosperms, and pteridophytes are examples of land plants. In certain situations, fungal relationships may be host specific.

a) **Improve Crop quality**: Mycorrhizal fungi significantly improve plants' capacity to absorb phosphorus and other nutrients that are relatively immobile and present in low concentrations in the soil solution. Fungi play an essential role in the uptake of various nutrients by the host plant. Zinc nutrition is the most frequently noted as affected by this association, although improvements in the absorption of copper (Cu), iron, nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg) have also been documented. Mycorrhizal relationships may enhance water uptake, thereby increasing drought resistance. In many cases, plants under drought stress that are mycorrhizal have higher rates of both water and nutrient uptake compared to those that are not mycorrhizal. The fungal filaments can modify the water potential in plants, helping to alleviate moderate drought stress, but their effectiveness diminishes under more severe drought conditions (Kaur et al. 2014).

b) **Drought stress tolerance:** enabling watering decrease: Drought stress greatly hampers the growth and development of plants by triggering oxidative stress, compromising membrane integrity, altering plant water relations, and hindering nutrient uptake, along with impacting photosynthetic activity. Arbuscular mycorrhizal fungi help preserve membrane integrity, enhance plant water content, and improve the uptake of both water and nutrients, as well as boost water use efficiency, thereby fostering plant growth in drought conditions. Additionally, AMF safeguards the photosynthetic machinery from oxidative stress caused by drought and enhances photosynthetic efficiency, along with the accumulation of osmolytes, phenols, and hormones, while decreasing the levels of reactive oxygen species through elevated antioxidant activity and gene expression, which equips plants with tolerance against drought stress. Consequently, it is crucial to comprehend the function of Arbuscular mycorrhizal in plants that are cultivated under drought stress.

c) **In minimising the chemical based fertilizers**: Arbuscular mycorrhizal fungi are recognized for forming symbiotic associations with around 80% of land plant species. Their beneficial effects on the degradation of soil organic matter and nutrient cycling enhance soil fertility, improve plant nutrition, increase water absorption, stabilize soil aggregates, reduce salinity and drought stress, and boost overall crop growth and productivity, making them valuable as bioinoculants for sustainable agriculture. Thus, Arbuscular mycorrhizal fungi can serve as an amendment to promote long-lasting soil fertility, enhance plant nutrition, and improve crop productivity and yield quality, which aids in agricultural sustainability and the revitalization of agro-ecosystems. Furthermore, products derived from mycorrhizae are frequently more economical than traditional fertilizers, especially in areas facing phosphorus depletion in the soil (Navarro et al, 2024)

d) **Salinity stress tolerance:** The interaction between arbuscular mycorrhizal fungi (AMF) and plants experiencing salt stress enhances the selective uptake of certain elements such as calcium (Ca) and potassium (K), while limiting the uptake of others like sodium (Na+), thereby improving water utilization efficiency and promoting the growth of the host plant. In saline conditions, the colonization of plant roots and soil by AMF can enhance the soil's rhizosphere environment by boosting the absorption of organic carbon, increasing the availability of nitrogen (N), phosphorus (P), and potassium (K), improving organic matter levels, adjusting soil pH, and mitigating soil erosion. Furthermore, AMF enhances the absorption of water and nutrients for the host plants by establishing an extensive network of hyphae and spreading the mycorrhizal fungi beyond the rhizosphere (Boorboori et. al. 2025) (Figure 3).

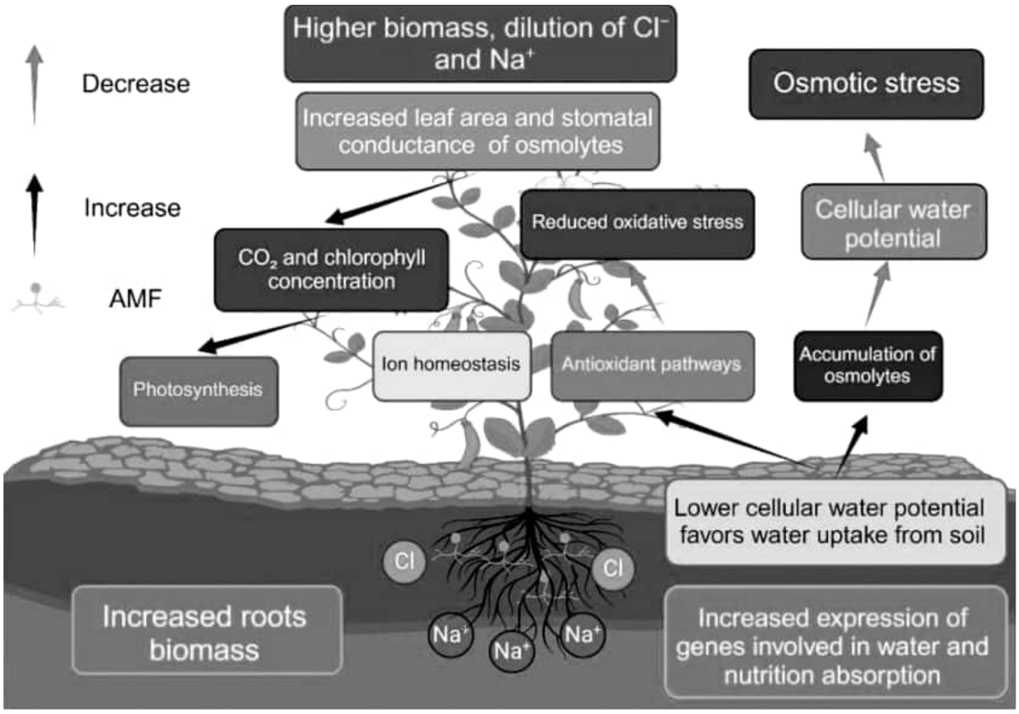

Figure 3. Advantages of using arbuscular mycorrhizal fungus to colonizing plant roots in saline soils (Sources: Gupta et al. 2021)

e) **Enhance the soil quality and nutrient cycling:** Enhancing the turnover and recycling of nutrients, a crucial aspect for the sustainability and productivity of agro-ecosystems, relies on the effective functioning of a network of plant-soil interactions that includes microbial populations. Both beneficial symbionts and saprophytic microorganisms that inhabit the root-soil interfaces, known as the rhizosphere, or the soil associated with plants, are acknowledged as key contributors to nutrient cycling, availability, and absorption. Among the beneficial symbionts, arbuscular mycorrhizal (AM) fungi represent one of the most significant groups of soil microorganisms because once they form a symbiotic relationship with most plant species, they improve the plants' nutrient uptake capabilities. Saprophytic microorganisms are valued for their capacity to enhance nitrogen (N) fixation and/or phosphorus (P) mobilization, which are vital processes for maintaining plant productivity. The establishment of mycorrhizae alters the biological and physical-chemical characteristics of the rhizosphere, leading to the formation of what is known as the mycorrhizosphere. The mycorrhizosphere of leguminous plants is particularly important as it also encompasses the symbiosis with nitrogen-fixing nodulating rhizobial bacteria. In this overview of the interactions within the mycorrhizosphere concerning nutrient cycling, the key microorganisms are first described, followed by an examination of the mechanisms that enable AM plants to acquire nutrients (Azcon-Aguilar and Barea, 2025)

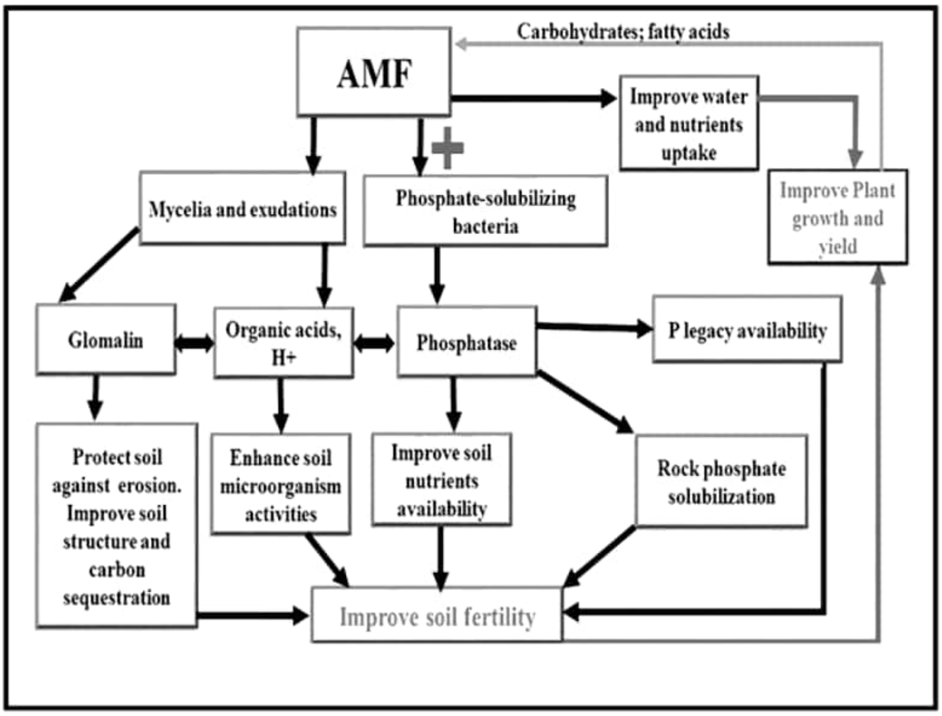

Figure 4. Role of Mycorhiza in maintaining soil fertility (Sources: Fall, 2022)

4. Prospects for the Future:

The complicated interactions between AMF and plants have changed over more than 500 million years. It is very difficult to separate the effects of AMF in agroecosystems. Although the results of lab or glasshouse experiments that concentrate on specific symbiotic elements are helpful, they do not provide the whole picture because agricultural systems are actually complex, full of multitrophic interactions as well as economic and environmental pressures that need to be carefully taken into account. Crop yields are important for food and economic security, but they shouldn't come at the expense of agricultural systems' long-term productivity. The influence of mycorrhizal fungi on the resilience and overall performance of soil ecosystems should always be taken into account, even though the data regarding mycorrhizal-mediated plant growth responses is occasionally inconclusive.Having access to appropriate and trustworthy commercial inoculants is crucial for farmers trying to change their farming practices to be less harmful to the environment. In addition to promoting AMF, practices like reduced tilling, the use of cover crops, and avoiding artificial fertilizers are anticipated to gain importance for improving food production in a sustainable manner due to their other advantages.

5. Conclusion

Mycorrhizal fungi are essential to agriculture because they improve soil structure, increase plant tolerance to diseases and environmental stressors, and improve nutrient and water intake. It has been estimated that plants colonized by AM may contribute 10–20% of their photosynthetically fixed carbon to their fungal partners in natural settings. This is undoubtedly a substantial energy input into the soil ecosystem, and the carbon may be essential for mycorrhizosphere-associated microbes. There are many advantages to incorporating them into farming methods, such as lower fertilizer consumption, better crop quality, increased soil health, and environmental sustainability. Mycorrhizae's role in agriculture will grow in significance as we look for sustainable ways to produce food on a global scale.

References

Azcón-Aguilar, C., & Barea, J. M. (2015). Nutrient cycling in the mycorrhizosphere. *Journal of Soil Science and Plant Nutrition, 25*(2), 372–396

Benami, M., Isack, Y., Grotsky, D., Levy, D., & Kofman, Y. (2020). The economic potential of arbuscular mycorrhizal fungi in agriculture. In H. Nevalainen (Ed.), *Grand challenges in biology and biotechnology* (pp. 239–279). Springer.

Boorboori, M. R., & Lackóová, L. (2025). Arbuscular mycorrhizal fungi and salinity stress mitigation in plants. *Frontiers in Plant Science, 15,* 1504970.

Brar, B., Bala, K., Saharan, B.S. Kumar, S.,P., Dhuan, S., J., (2024)) Bio-boosting agriculture: Harnessing the potential of fungi-bacteria-plant synergies for crop improvement. *Discov. Plants* 1, 1-21

Chaudhary, T., Dixit, M., Gera, R., Shukla, A. K., Prakash, A., Gupta, G., & Shukla, P. (2020). Techniques for improving formulations of bioinoculants. *3 Biotech*, *10*, 199.

Cramer, W., Holten, J. I., Kaczmarek, Z., Martens, P., Nicholls, R. J., Öquist, M., Rounsevell, M. D. A., & Szolgay, J. (2022). Climate change 2001: Impacts, adaptation and vulnerability (Ch. 13 Europe). In *IPCC Report* (pp. 643–692).

Das, S and Sarkar S. (2024). Arbuscular mycorrhizal fungal contribution towards plants resilience to drought conditions. *Front. Fungal Biol.* 95, 1-10

Ejersa, M. T. (2021). The role of arbuscular mycorrhizal fungi on agricultural crop productivity and ecosystem service: A review. *International Journal of Agroforestry and Silviculture*, *9*, 1–9.

Fall, A. F., Nakabonge, G., Ssekandi, J., Founoune-Mboup, H., Apori, S. O., Ndiaye, A., Badji, A., & Ngom, K. (2022).

Frank, A. B. (1885). Ueber die auf Wurzelsymbiose beruhende Ernährung gewisser Bäume durch unterirdische Pilze. *Berichte der Deutschen Botanischen Gesellschaft*, *3*, 128–145.

Gerten, D., Heck, V., Jägermeyr, J., Bodirsky, B. L., Fetzer, I., Jalava, M., Kummu, M., Lucht, W., Rockström, J., Schaphoff, S., & Schellnhuber, H. J. (2020). Feeding ten billion people is possible within four terrestrial planetary boundaries. *Nature Sustainability*, *3*, 200–208.

Gupta, S., Schillachi, M., Waler, R., Smith, P., M.m Watt, M., Roessner, U., (2021). Alleviation of Salinity stress in plants by endiphytic plant-fungal symbiosis: Current knowledge, perspectives and future direction. *Plant Soil 461*, 219-244

Harley, J. L., & Smith, S. E. (1983). *Mycorrhizal symbiosis*. Academic Press.

Kaur, R., Singh, A., & Kang, J. S. (2014). Influence of different types of mycorrhizal fungi on crop productivity. *Current Agriculture Research Journal, 2*(1),

Khanna, R., & Gupta, S. (2018). Agrochemicals as a potential cause of groundwater pollution: A review.

International Journal of Chemical Studies, *6*, 985–990.

Kotopoulou, S., Zampelas, A., & Magriplis, E. (2021). Dietary nitrate and nitrite and human health: A narrative review by intake source. *Nutrition Reviews*, *80*, 762–773.

Maitra, S., Brestic, M., Bhadra, P., Shankar, T., Praharaj, S., Palai, J. B., Shah, M. M. R., Barek, V., Ondrisik, P., Skalický, M., & Hossain, A. (2022). Bioinoculants—Natural biological resources for sustainable plant production. *Microorganisms*, *10*, 1–35.

Morin, E., Miyauchi, S., Clemente, S. H., et al. (2019). Comparative genomics of *Rhizophagus irregularis*, *R. cerebriforme*, *R. diaphanus* and *Gigaspora rosea* highlights specific genetic features in Glomeromycotina. *New Phytologist*, *222*(3), 1584–1598.

Navarro, J. M., & Morte, A. (2024). Arbuscular mycorrhizal fungi as biofertilizers to increase the plant quality of sour-orange seedlings. *Agronomy*, *14*(1), 230.

Parrón, T., Requena, M., Hernández, A. F., & Alarcón, R. (2014). Environmental exposure to pesticides and cancer risk in multiple human organ systems. *Toxicology Letters*, *230*, 157–165.

Roles of arbuscular mycorrhizal fungi on soil fertility: Contribution in the improvement of physical, chemical, and biological properties of the soil. *Frontiers in Fungal Biology*, *3*, 1–11.

Santoyo, G., Gamalero, E., & Glick, B. R. (2021). Mycorrhizal-bacterial amelioration of plant abiotic and biotic stress. *Frontiers in Sustainable Food Systems*, *5*, Article 672881.

Shipley, J. R., Twining, C. W., Taff, C. C., Vitousek, M. N., Flack, A., & Winkler, D. W. (2020). Birds advancing lay dates with warming springs face greater risk of chick mortality. *Proceedings of the National Academy of Sciences of the United States of America*, *117*, 25590–25594.

Tang, H., Hassan, M. U., Feng, L., Nawaz, M., Shah, A. N., Qari, S. H., Liu, Y., & Miao, J. (2022). The critical role of arbuscular mycorrhizal fungi to improve drought tolerance and nitrogen use efficiency in crops. *Frontiers in Plant Science*, *13*, 919166.

Ullah, H., Santiago-Arenas, R., Ferdous, Z., Attia, A., & Datta, A. (2019). Improving water use efficiency, nitrogen use efficiency, and radiation use efficiency in field crops under drought stress: A review. *Advances in Agronomy*, *157*, 109–157.

United Nations, Department of Economic and Social Affairs, Population Division. (2019). *World population prospects 2019: Highlights*. https://www.ncbi.nlm.nih.gov/pubmed/1228321

Yadav, R., Ror, P., Rathore, P., & Ramakrishna, W. (2020). Bacteria from native soil in combination with arbuscular mycorrhizal fungi augment wheat yield and biofortification. *Plant Physiology and Biochemistry*, *150*, 222–233.