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ROLE OF MYCORRHIZAL FUNGI IN CARBON SEQUESTRATION: MECHANISMS, ECOLOGICAL IMPACT, AND POTENTIAL FOR CLIMATE CHANGE MITIGATION

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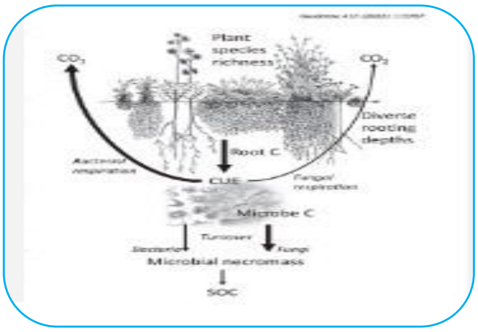
ABSTRACT

The mycorrhizal fungi are crucial symbiotic organisms that significantly contribute to carbon sequestration and thus are essential to global carbon cycles and climate change mitigation. Symbioses between mycorrhizal fungi and roots of plants allow them to transfer atmospheric carbon assimilated into soil organic matter through photosynthesis in plants. This review discovers the mechanisms by which mycorrhizal fungi impact carbon dynamics in soils, including transfer pathways for carbon, aggregation and stabilization of organic carbon, focusing on different roles of arbuscular and ectomycorrhizal fungi. All these consider the ecological importance of mycorrhizal fungi with special attention given to their contributions to the health of soil, resilience in plants and overall productivity in ecosystems-thus an enhancement of carbon retention in various ecosystems. Other factors that are considered important in determining the efficiency of mycorrhizal carbon storage are environmental factors, including soil properties, climate variability, and land-use changes. Other emerging applications of mycorrhizal fungi in managed ecosystems, such as agriculture, agroforestry, and reforestation, are promising avenues for carbon farming and sustainable land management. With integration of mycorrhizal management practices, carbon credit markets may leverage natural carbon sequestration and integrate ecological and economic goals. However, quantifying mycorrhizal contributions across ecosystems and understanding the resilience of fungal networks to environmental change remains challenging. More research is needed to realize the full potential of mycorrhizal fungi in global carbon sequestration strategies. This review underlines the importance of mycorrhizal fungi in the context of climate mitigation and has practical implications and opportunities for future research.



KEYWORDS: *Arbuscular Mycorrhizae, Carbon Sequestration, Climate Change Mitigation, Mycorrhizal Fungi, Soil Carbon Dynamics.*

1. INTRODUCTION

Fungi is the specialized most diversified association on heterotrophic organism and the second largest community after insect, on the earth (Singh and Singh, 2023a; Dwivedi et al., 2024a). Fungi refers to Kingdom Mycota, which has been broadly divided into two categories, i.e., macrofungi and microfungi. They are grouped into a single kingdom of Fungi. Fungi have thalloid body organization without forming tissues and organs (Singh and Singh, 2022). About 1.5 million fungal species are thought to exist in nature, although only about 50% of them have been identified to date (Singh et al., 2024). They show a variety of habitats in terrestrial ecosystems such as parasitic, saprophytic, or symbiotic (Dwivedi et al., 2024b). Mycorrhizal fungi are symbiotic partners with around 90% of terrestrial plants, possessing a very critical role in global carbon cycling and increasingly showing potential in carbon sequestration. Mycorrhizal fungi make highly complex networks with plant roots to eventually enable exchange between roots and shoots, thus impacting on plant health and resilience, as well as altering soil structure. The fungi are act as scavengers and also play an important role in ecological system as well as in biogeochemical cycles (Singh and Singh, 2023b). Indeed, most recent studies have highlighted the role of mycorrhizal associations in carbon dynamics, focusing especially on increasing soil organic carbon storage through complex biochemical and ecological processes (Smith & Read, 2018; Rillig, 2004). It is indeed becoming an important focus of research and policy setting because mycorrhizal fungi have the capability to sequester significant amounts of carbon while improving the health of the soil in a large-scale manner.

There are two large functional groups of mycorrhizal fungi relevant to carbon cycling: arbuscular mycorrhizal (AM) fungi and ectomycorrhizal (EM) fungi. AM fungi primarily colonize herbaceous plants and dominate grassland and tropical ecosystems in which they increase carbon retention in the soil through increased root biomass and stability. Instead, EM fungi are primarily associated with trees in boreal and temperate forests and can play an important role in stabilizing carbon over longer periods by contributing to organic matter formation and lowering carbon turnover rates (Smith & Read, 2018). With a twofold role in carbon allocation and soil stabilization, the mycorrhizal fungi clearly have had an important role in the ecosystem's carbon budgets and offer clues toward their possible uses in efforts at mitigating climate change.

Carbon is sequestered by mycorrhizal fungi through mechanisms other than simple biomass accumulation. They influence the aggregation and stabilization of organic matter by excreting glomalin, a glycoprotein associated with AM fungi, hence enhancing soil structure and hence protecting organic carbon from decomposition (Rillig et al., 2001). Additionally, EM fungi contribute to carbon sequestration through the production of recalcitrant compounds that prevent the quick decomposing of organic matter. In addition to its role in nutrient uptake, these extracellular enzymes produced by fungi transform soil carbon and influence carbon storage dynamics. This unique biochemical interaction between mycorrhizal fungi, plants, and soil stabilizes and enhances soil carbon storage.

Emerging evidence highlights the role of mycorrhizal fungi in ecological carbon sequestration by which these fungi not only directly sequester carbon but also increase plant productivity and resilience, thus contributing to carbon sequestration capacity in ecosystems as a whole. For example, by enhancing nutrient acquisition, mycorrhizal fungi increase photosynthesis capacity and growth that results in higher inputs of carbon into the ecosystems and further enhance carbon storage (Terrer et al., 2016). However, their role in supporting biodiversity and soil health underlies the resilience and stability of ecosystems related to climate disturbances. Thus, mycorrhizal fungi increasingly find their roles as a natural solution for scalable and sustainable carbon sequestration, providing an ecological tool for climatic change mitigation effects (Bardgett & van der Putten, 2014).

The mechanisms and ecological implications of mycorrhizal fungi on carbon sequestration are greatly important to take advantage of their potential in climate change mitigation. The present research currently focuses on quantifying specific contributions of different mycorrhizal types to carbon dynamics, assessment of resilience of such species under changing climate conditions, and ways of integrating them in land management and conservation practices. All things being equal, it is becoming increasingly evident that mycorrhizal fungi are an exciting, nature-based way in which carbon storage would be enhanced, especially when utilizing it in conjunction with conservation and reforestation activities (Johnson et al., 2017; Treseder & Holden, 2013). However, to realize this potential, researchers need to continue with further studies on the carbon-sequestering capabilities of mycorrhizal fungi in diverse ecosystems and under different types of environmental stresses.

2. TYPES OF MYCORRHIZAL FUNGI AND THEIR ROLES IN CARBON SEQUESTRATION

Mycorrhizal fungi significantly contribute to the carbon sequestration in diverse ecosystems because of the symbiotic relationships maintained with the plant roots. The two types of mycorrhizal fungi, arbuscular mycorrhizal (AM) fungi and ectomycorrhizal (EM) fungi, have distinct mechanisms in carbon sequestration, thus affecting soil carbon dynamics in different ways due to their ecological roles and biochemical interaction (Smith & Read, 2008). This understanding of the diffrent contributions of these mycorrhizal types to carbon sequestration would be a must in choosing strategies, which may be applied to exploit potential climate change mitigation, and carbon storage improvement techniques of terrestrial ecosystems (Terrer et al., 2016; Averill et al., 2014).

2.1 Arbuscular Mycorrhizal (AM) Fungi

Arbuscular mycorrhizal fungi, belonging to the phylum Glomeromycota, have been discovered to live in symbiosis with a wide number of herbaceous and non-woody plants of grassland, tropical, and agricultural ecosystems. AM fungi colonize the roots of the host plant by building branched structures called arbuscules within root cells; direct nutrient and carbon exchange becomes possible between the fungus and the host plant (Smith & Read, 2008). This promotes carbon sequestration as the fungi enable the enhancement of plant growth and, hence root biomass, directly increasing the levels of soil organic carbon (SOC) (Treseder & Turner, 2007).

AM fungi contribute to carbon stabilization through the production of glomalin; a glycoprotein that is a soil binder, increases aggregation, reduces erosion, and contributes to organic matter stability (Rillig et al., 2001). Glomalin-studded soil particles protect SOC from microbial decomposition to constitute an environment conducive to long-term carbon storage (Rillig, 2004). This glomalinmediated soil aggregation is highly efficient in grassland and agricultural soils dominated by AM fungi. Indeed, it possesses the potential of maintaining soil structure and carbon content (Rillig & Mummey, 2006). Studies reveal that glomalin contributes significantly to the pools of soil carbon and accounts for about 20% to 30% of SOC in AM-dominated ecosystems (Rillig et al., 2001).

2.2 Ectomycorrhizal (EM) Fungi

Ectomycorrhizal fungi are found primarily with woody plants in boreal and temperate forests, where they play a critical role for long-term carbon sequestration, stabilizing carbon in forest soils. In contrast to AM fungi, EM fungi form highly ramified mycelial associations surrounding the plant's roots and produce exogenous fungal organs called ectomycorrhizas, through which nutrient transfer can occur between the plant and fungus without invading root cells (Smith & Read, 2008). Contributions of EM Fungi to Carbon Sequestration EM fungi contribute to carbon sequestration through the formation of recalcitrant compounds that delay the breakdown of organic matter, thereby increasing the residence time of carbon in forest soils (Clemmensen et al., 2013; Phillips et al., 2013).

Besides releasing inorganic nitrogen through decomposition, EM fungi further break down complex organic compounds in soils through the production of various enzymes that release and allow for the uptake of nitrogen and other nutrients. Nevertheless, this enzymatic activity indirectly impacts carbon sequestration by affecting soil organic matter dynamics. In the gradual decomposition of organic material, EM fungi promote the accumulation of partially decomposed organic matter, contributing to pools of soil carbon and generally slowing overall carbon turnover (Averill et al., 2014). It has been shown that EM-associated forests have higher carbon storage per unit area compared to AM-associated forests, and the EM fungi play a crucial role in sequestering carbon within boreal and temperate ecosystems (Averill et al., 2014; Clemmensen et al., 2013).

2.3 Comparison of AM and EM Fungi in Carbon Sequestration

AM and EM fungi, two different carbon sequestration strategies, have evolved to thrive in specific environments where they were dominant. Even if the AM fungi, that is common on nutrient-poor grasslands and in tropical regions, mainly influence carbon sequestration due to a better soil structure and organic carbon protection through glomalin production (Treseder & Turner, 2007). On the contrary, EM fungi in temperate and boreal forests contribute to carbon sequestration by slowing down the decomposition rate of organic material through the production of humus and other stable organic compounds (Clemmensen et al., 2013; Phillips et al., 2013).

This distinguishes the various strategies that should be employed in ecosystem-specific application of mycorrhizal fungi to sequester carbon. For instance, augmenting the AM fungi in agricultural landscapes stabilizes carbon in soil through increased production of glomalin, whereas conserving EM-dominated forests increases long-term storage by reducing carbon turnover (Terrer et al., 2016; Johnson et al., 2017). These microorganisms assume significant roles due to their varied functions; therefore, carbon management schemes have centered on the particular carbon-cycling activities of various ecosystems.

2.4 Examples of Mycorrhizal Fungi that Help in Carbon Sequestration

Such mycorrhizal fungi species strongly sequester carbon within plant ecosystems given that they have a symbiotic relationship with the plants and their effects on soil carbon cycling. Although both arbuscular mycorrhizal (AM) fungi and ectomycorrhizal (EM) fungi play an important role in this regard, they function through somewhat different ecological mechanisms depending upon the ecosystem in which they reside. These microbes influence carbon storage by impacting soil aggregation, stabilization of organic matter, and plant development. We detail some model species of AM and EM fungi that enhance carbon storage in soils in different ecosystems (Smith & Read, 2008; Averill et al., 2014).

2.4.1 Rhizophagus irregularis (Arbuscular Mycorrhizal Fungi)

The globally well-studied AM fungus *Rhizophagus irregularis*, in relation to carbon sequestration potential, has a wide range of occurrences in grasslands and agricultural ecosystems (Field et al., 2019). The symbionts formed inside this species are beneficial for several herbaceous plants to enhance their biomass and, in consequence, elevate SOC levels by better nutrient uptake. In addition, *R. irregularis* produces glomalin, a glycoprotein that enhances soil aggregation, protecting organic carbon from rapid microbial decomposition (Rillig, 2004; Treseder & Turner, 2007). The protective role of glomalin is especially important in agricultural systems where soil disturbance is common as it helps stabilize soil organic matter and enhance long-term carbon retention (Rillig et al., 2001).

2.4.2 Pisolithus tinctorius (Ectomycorrhizal Fungi)

One of the most common EM fungi found in trees, such as pine, oak, and eucalyptus, and in temperate and boreal forests, is *Pisolithus tinctorius*. The scientists were interested in this fungus because it makes a large fraction of the carbon sequestration in the soils of the forests (Smith & Read, 2008). Such an EM fungus as *P. tinctorius* helps sequester a greater amount of soil carbon through the nutrient exchange taken from trees and facilitate greater increases in tree growth to assimilate more carbon into biomass (Clemmensen et al., 2013). Furthermore, *P. tinctorius* produces recalcitrant compounds that slow down organic matter decomposition, thus adding to the stable carbon pool in forest soils (Averill et al., 2014; Phillips et al., 2013).

2.4.3 Glomus intraradices (Arbuscular Mycorrhizal Fungi)

Amongst the AM fungi that help sequester carbon is *Glomus intraradices*, the most common type of AMF, which typically colonizes roots in grasslands and agricultural ecosystems. *G. intraradices* is believed to enhance the structure of soil and the amount of organic matter it retains by producing glomalin and improving the aggregation of soil. These mechanisms result in reduced soil erosion and an increased ability for organic carbon to be retained in topsoil, hence *G. intraradices* becomes particularly useful in a sustainable agriculture system (Rillig et al., 2001).

2.4.4 Cenococcum geophilum (Ectomycorrhizal Fungi)

Cenococcum geophilum is an ectomycorrhizal fungus that is often associated with tree species from temperate to boreal forests. It tolerates drought and persists under a range of environmental stressors, which makes it an important component in stable forest ecosystems. geophilum increases recalcitrant organic matter production, and hence slows decomposition rates; these accelerate the long-term storage of carbon in forest soils (Clemmensen et al., 2013). Its persistence and resilience enhance the stability of soils and underpin a significant proportion of the carbon cycle of forest regions.

2.4.5 Laccaria bicolor (Ectomycorrhizal Fungi)

Laccaria bicolor is the other ectomycorrhizal fungus that is also very widespread among coniferous trees in temperate forests. *L. bicolor* is reported to facilitate carbon sequestration as it aids the growth of plants and enhances carbon in soil through more inputs into the carbon pool. The production of extra-cellular enzyme by this fungus breaks organic compounds, reduces the rate of their decomposition, thereby causing accumulation of stable carbon forms hence regulating the storage of soil carbon (Phillips et al., 2013). Research on *L. bicolor* indicates its potential in carbon management strategies for forested ecosystems designed toward maximum long-term retention of carbon (Averill et al., 2014).

3. MECHANISMS OF CARBON SEQUESTRATION BY MYCORRHIZAL FUNGI

These mycorrhizal fungi play some crucial roles in the storage of carbon in ecosystems through several mechanisms, which include increasing stabilization of soil carbon, retention of organic matter, and feeding back carbon into the soil. There exist two types of mycorrhizal fungi, arbuscular mycorrhizal (AM), and ectomycorrhizal (EM). They both operate by differing pathways and host plant interaction to effect a change in soil carbon dynamics and encourage the storage of carbon over long periods. These mechanisms position mycorrhizal fungi as important players in any climate change mitigation effort, because they can significantly alter carbon cycling at ecosystem scales (Clemmensen et al., 2013; Smith & Read, 2008).

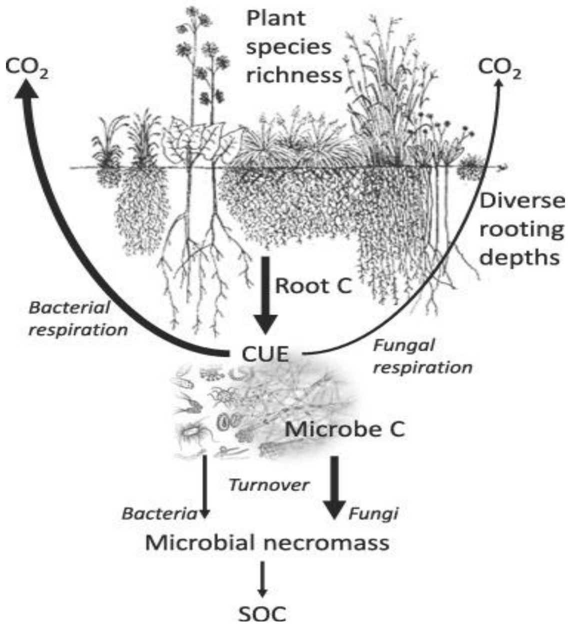


Figure-1. Role of Mycorrhizal Microbes in Carbon Sequestration

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3.1 Carbon Allocation from Host Plants to Fungi

The most important mechanism for sequestration by mycorrhizal fungi is the transfer of carbon from the plant to the fungal partners. Mycorrhizal fungi invade root systems of plants in exchange for critical nutrients, for example, phosphorus and nitrogen, provided by the host from photosynthetically fixed carbon (Treseder & Allen, 2000; Smith & Read, 2008). The produced carbon allocation will build highly extensive hyphal networks in the soil, which contribute to the soil organic carbon pools. For instance, the EM fungi can create a thick mycelial network around the roots of trees hence facilitating carbon storage in boreal and temperate forests.

AM fungi play a related function in moving carbon to soils in grasslands and agricultural systems. Even though they have less direct contribution towards the organic carbon in the soil compared to EM fungi, they promote soil structure through root biomass growth that indirectly impacts carbon storage (Rillig et al., 2001). Further, these fungi stabilize soil aggregates, therefore, forming physical barriers to prevent organic matter from microbes attacks and degradation processes (Rillig & Mummey, 2006).

3.2 Production of Recalcitrant Compounds

It has been proposed that mycorrhizal fungi play a key role in carbon storage by producing recalcitrant compounds, such as those produced by AM fungi, including glomalin, and melanin-like compounds produced by EM fungi. These compounds resist microbial degradation and are important for stabilizing carbon in soils. The C-binding proteins glomalin produced by AM fungi cause it to bind to soil particles thus improving soil aggregation and protecting organic matter from microbial decomposers within the soil aggregates (Rillig et al., 2001; Treseder & Turner, 2007). This protects organic carbon within soils, especially in those dominated by AM fungi, as is the case for most grasslands and tropical forests.

That in EM fungi, such melanin-like compounds and other complex organic substances stabilize soil organic matter by the slowing down of the decomposition of the organic material (Phillips et al., 2013; Clemmensen et al., 2013). The production of recalcitrant compounds, thus favoring carbon sequestration through long-term organic matter accumulation, particularly in temperate and boreal forest soils where decomposition rates are relatively slow (Averill et al., 2014).

3.3 Formation of Soil Aggregates

Mycorrhizal fungi indeed modify soil structure through the formation of soil aggregates that will become crucial in controlling carbon sequestration by forming a physical matrix that effectively shields organic matter from rapid decomposition. AM fungi are particularly effective at enhancing soil aggregation by virtue of the production of glomalin that ties together soil particles and enables stable aggregate formation (Rillig & Mummey, 2006; Treseder & Allen, 2000). These aggregates trap organic carbon, hence denying access and availability to microbes for its degradation, thus improving the soil's retention of carbon. Research has shown that carbon held within AM fungal aggregates could substantially compose soil organic carbon in the ecosystem dominated by AM (Rillig, 2004).

EM fungi also contribute to soil aggregation by virtue of the extensive mycelial networks that physically hold soil particles together in a stable structure that is favorable to carbon storage. This function has been identified to be of outstanding significance in forest ecosystems where EM fungi dominate, as these fungi are known to suppress soil erosion, enhance soil stability, and support long-term organic matter accumulation in soil matrices (Averill et al., 2014; Clemmensen et al., 2013).

3.4 Influence on Soil Microbial Community Dynamics

Indirectly, mycorrhizal fungi can influence carbon sequestration by their influences on soil microbial community dynamics, including decomposers. For instance, through competitive assimilation of nitrogen and other mechanisms, EM fungi may suppress the activities of saprotrophs in the soil, thereby slowing down the decomposition rate that leads to persistent presence of organic material in soil, thereby contributing to the longer time-scale carbon storage (Averill et al., 2014). Furthermore, by slowing down decomposition rates, EM fungi help stabilize organic compounds that are crucial for longer time-scale carbon storage (Phillips et al., 2013).

AM fungi also affect the soil microbial dynamics by engaging in mutualistic relationships with soil bacteria, such as nitrogen-fixing bacteria. The mutualistic associations improve fertility, increase plant growth, and indirectly enhance carbon sequestration through the enhanced plant biomass and root development that is a source of carbon in the soil (Smith & Read, 2008). This synergy among mycorrhizal fungi and soil microbial communities emphasizes the multidimensional roles that these fungi play in stabilizing and storing carbon within soil ecosystems (Terrer et al., 2016).

4. ECOLOGICAL IMPACT OF MYCORRHIZAL FUNGI IN CARBON SEQUESTRATION

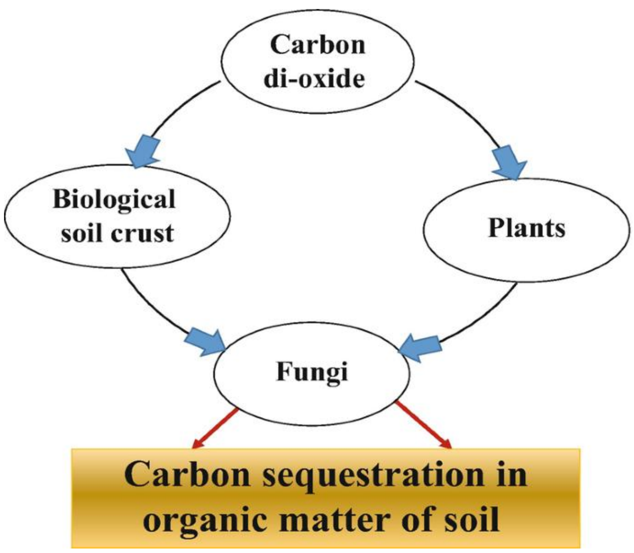
The mycorrhizal fungi play crucial roles in the carbon cycle and storage; through increased plant productivity, contribution to soil structure stability, and nutrient cycling influences, they mold the carbon dynamics of terrestrial environments to help mitigate climate change. Arbuscular mycorrhizal (AM) and ectomycorrhizal (EM) fungi sequester carbon ecologically differently, complementing each other for stabilization and promotion of sustainable plant communities in soils (Smith & Read, 2008; Averill et al., 2014).

4.1 Enhanced Plant Growth and Carbon Input

Mycorrhizal fungi increase plant biomass by increasing nutrient uptake, thereby increasing carbon inputs to the soil through root exudates and plant litter. In grasslands, AM fungi increase phosphorus availability; phosphorus is a very critical nutrient for plant growth, hence increasing photosynthetic rates and the carbon that plants fix in soils (Treseder & Allen, 2000; Rillig, 2004). It is observed that EM fungi, which are widespread in forests, enhance nutrient accumulation for trees due to massive enhancement of root biomass and input of carbon in soil (Phillips et al., 2013). Further investigation indicated that forests rich in EM fungi have more stable soil organic carbon due to continuous inputs from long-lived woody plant species (Clemmensen et al., 2013).

4.2 Soil Structure Stability and Organic Matter Retention

Both AM and EM fungi play crucial roles in maintaining soil structure stability, which is paramount for carbon sequestration through reduced soil erosion and increased organic matter retention. AM fungi promote soils aggregation when it secretes glomalin, a sticky glycoprotein that bonds soil particles together into stable aggregates resistant to rapid microbial decomposition. This is particularly important for agricultural ecosystems, as there is frequently soil disturbance and, in the case of unstable soils, it will be a potential carbon loss. EM fungi also enhance soil stability for forest ecosystems by forming vast hyphal networks that physically lock together soil particles combined with contributing to the development of humus layers, furthering organic matter accumulation and carbon preservation (Averill et al., 2014).



4.3 Influence on Soil Carbon-to-Nitrogen Ratios

In this regard, mycorrhizal fungi alter the C:N ratios of the soils and thereby the long-term stability of carbon within the ecosystems. This can be related to the response of EM fungi that tend to force soil systems towards higher C:N ratios by slowing nitrogen cycling. Thus, owing to effective competition for nitrogen with saprotrophic or decomposer microbes, these fungi manage to limit the availability of nitrogen, further slowing down decomposition processes for organic matter (Phillips et al., 2013; Averill et al., 2014). This dynamic stands out particularly in forests where a higher C:N ratio of soil is associated with higher carbon storage, likely as a result of fewer microbial activities and lower decomposition rates. Competition between EM fungi and decomposers indirectly facilitates long-term carbon sequestration by setting up an environment for the gradual accumulation of organic carbon.

4.4 Resilience to Environmental Stressors

The mycorrhizal fungi improve resistance of the ecosystem to environmental stresses, such as drought and nutrient deficiencies, that increase carbon sequestration under changing climatic conditions. Its forms can survive well in nutrient poor and drought prone soils, including those found in boreal and temperate forests (Brunner et al., 2019). Their resilience supports forest stability and carbon storage under climatic stress, as they help keep trees productive and resistant to adverse conditions. AM fungi similarly help in ecosystem resilience by providing support to soil aggregation and preventing the erosion of stored carbon in grasslands and agricultural ecosystems (Rillig et al., 2001).

4.5 Synergies with Soil Microbial Communities

Mycorrhizal fungi interact with a diverse community of soil microorganisms, and synergistic associations enhance nutrient cycling and carbon stabilization. For instance, EM fungi are in mutualistic relationships with nitrogen-fixing bacteria. The interaction enhances the availability of nitrogen to the plants, indirectly increasing carbon inputs into the soil (Smith & Read, 2008). In addition, AM fungi increase microbial activity in the rhizosphere; the microbial communities associated with roots break down organic matter and make nutrients available and hence maintain a balanced condition with adequate carbon sequestration without reducing soil fertility (Terrer et al., 2016).

5. ENVIRONMENTAL FACTORS AFFECTING MYCORRHIZAL CARBON SEQUESTRATION

This, therefore, means that environmental aspects decide the efficiency of mycorrhizal fungi in carbon sequestration. The impact of temperature, soil moisture, nutrient availability, and pH levels affects mycorrhizal colonization and function both directly and indirectly as it impacts the storage of carbon in the ecosystem (Treseder, 2004; van der Heijden et al., 2015). Climate-driven fluctuations in these factors further impact the stability and carbon reservoir quantity of carbon sequestration, hence making mycorrhizal activity both responsive and regulating in terms of terrestrial carbon cycling.

5.1 Temperature and Carbon Dynamics

The temperature affects the physiology and metabolic rates of mycorrhizal fungi directly and their ability to sequester carbon. A high temperature accelerates the decomposition of organic matter, which allows the release of carbon into the atmosphere and therefore undermines the potential for carbon sequestration. However, moderate elevation in temperature can also increase fungal biomass and activity, potentially improving carbon sequestration (Averill et al., 2014). The temperature sensitivity of mycorrhizal carbon dynamics varies by fungus type and for ectomycorrhizal (EM) fungi, with the boreal forests showing increased carbon storage under cooler climate conditions, tolerant to this relative climate compared to other types of fungi (Clemmensen et al., 2013; Fernandez et al., 2016).

5.2 Soil Moisture and Drought Conditions

Soil moisture is significant to mycorrhizal in survival as well as functioning. Both AM and EM fungi need a suitable soil moisture content to maintain the symbiosis with host plants for proper exchange of nutrients and carbon. Fungi as well as plant activity declines during drought periods and subsequently contributes to lower carbon input in the soil system (Allen, 2007). Contrarily, some EM fungi of temperate and boreal regions have therefore become adapted to operate well with low moisture content, thereby increasing the resilience of forests to droughts due to climate, and ensuring a better stability in carbon storage (Brundrett & Tedersoo, 2018; Steidinger et al., 2019).

5.3 Nutrient Availability and Mycorrhizal Efficiency

Nutrient availability, especially nitrogen and phosphorus, has impacts on mycorrhizal functioning and their role for carbon sequestration. High levels of the availability of nitrogen often result from human influences such as agricultural runoff that reduce the importance of mycorrhizae for plant nutrition and subsequently reduce carbon inputs through root exudates and fungal biomass (Terrer et al., 2016). Mycorrhizal fungi take on a pivotal role in the maintenance of plant health in nutrient-poor soils, as they enhance the uptake of nutrients and enhance carbon transfer to the soil (Phillips et al., 2013). Nutrient-limited Forest ecosystems promote mutualistic interactions that favor carbon sequestration, especially when phosphorus levels are naturally low, fostering strong AM fungal associations (Smith & Read, 2008).

5.4 Soil pH and Mycorrhizal Abundance

Mycorrhizal colonization rates and fungal diversity are significantly affected by soil pH, which dictates its potential impact on carbon sequestration. Acid soils, usually grassland or forest ecosystems, are preferred by most EM fungi that thrive well under such conditions and contribute significantly to carbon storage through slow decomposition and accumulation of organic matter (Treseder, 2004). Neutral to slightly alkaline soils, which include grasslands and some agricultural soils, are preferred by AM fungi in more numbers. Variation in soil pH therefore impacts what type of mycorrhizal fungus might be present and the corresponding dynamics in terms of carbon sequestration (van der Heijden et al., 2015).

5.5 Land Use Changes and Habitat Disturbances

Human activities such as deforestation, agriculture and urbanization have been proven to interfere with mycorrhizal networks hence lowering the potential to capture carbon. The removal of plant cover and soil disturbances decrease the species richness and biomass of mycorrhizae that lowers the potential for long-term carbon storage in soils (Rillig, 2004). Farming methods such as reduced tillage and cover cropping that maintain soil health support AM fungal colonization. This can enhance carbon sequestration for managed lands (Verbruggen & Kiers, 2010). This is because conservation and reforestation plays an important role in the maintenance of fungal diversity and the ecological processes that sustain maximum carbon sequestration in both forested and agricultural ecosystems (Brundrett & Tedersoo, 2018).

6. MYCORRHIZAL FUNGI IN MANAGED ECOSYSTEMS AND CARBON FARMING

Mycorrhizal fungi play a central role in improving soil health and enhancing carbon sequestration in managed ecosystems, such as agricultural landscapes and carbon farming systems. Carbon farming has emerged as an essential component of the global carbon cycle, managing ecosystems that capture and store atmospheric CO_2 in soil and vegetation. Because these systems depend on the relationships that are unique to mycorrhizal fungi, they improve the fertility of soil, enhance the resilience in plants, and contribute significantly to the storage of carbon in soils (Lehmann & Rillig, 2015; Bender et al., 2014).

6.1 Role of Mycorrhizal Fungi in Agricultural Systems

Mycorrhizal fungi are fungi commonly associated with agriculture and known to improve plant growth, acquisition of nutrients, and tolerance to stress. The arbuscular mycorrhizal (AM) fungi, among others, allow for the uptake of nutrients and water through the increase in size of the hyphal networks in the soil that go beyond the root zone (Smith & Read, 2008). This increased nutrient cycling increases crop yields while bringing higher carbon deposition in soils, both through increased plant biomass and root exudation that build stable organic matter pools (Rillig, 2004; Verbruggen & Kiers, 2010).

6.2 Carbon Farming and Mycorrhizal Integration

Mycorrhizal fungi become one of the prime biological approaches for carbon capture through carbon farming. Minimum tillage, rotation, and cover cropping create optimum conditions for AM fungi, so these can thrive in agricultural soil (Wilson et al., 2009). This is mainly because mycorrhizal inoculation on crops may prove to be the highest benefits that the fungi can possibly offer, especially in microbial communities depleted soils that are a result of conventional practices (Hijri, 2016). These long-term storage carbon practices are related to the fact that they usually enhance the accumulation of carbon-rich compounds in soil organic matter that promotes soil resilience and productivity (Bender et al., 2015).

6.3 Benefits and Challenges in Managed Forests

On the other hand, mycorrhizal fungi are part of managed forests and are important in cycling nutrients to the forest system. They play a role in carbon sequestration in biomass and soil when it disintegrates since EM fungi enhance carbon sequestration by decomposition rate slowing through recalcitrant compounds and facilitating carbon storage in the organic layer of soils of the forests (Clemmensen et al., 2013). These are significant in boreal and temperate forests, where EM fungi form symbioses with dominant tree species and account for a high proportion of soil carbon storage (Averill et al., 2014; Fernandez et al., 2016). In sharp contrast, managed forests struggle to conserve mycorrhizal diversity due to logging and habitat fragmentation, which can disrupt fungal networks and reduce carbon storage capacities (Brundrett & Tedersoo, 2018).

6.4 Challenges of Mycorrhizal Application in Managed Ecosystems

Application of mycorrhizal fungi in managed ecosystems does present practical as well as ecological challenges. Fungal effectiveness might be variable across soil types, climates, and plant species, which may complicate large-scale applications of mycorrhizal-based carbon farming practices (Verbruggen & Kiers, 2010). In addition, mycorrhizal inoculation in all crop systems is not cost-effective; further study is necessary in order to determine the long-term impacts on ecosystem stability (Johnson et al., 2013). Despite these challenges, active research and innovation of fungally inoculated amendments combined with improved soil management technique are constantly enhancing the management of mycorrhizal fungi to promote utilization for better carbon sequestration in managed ecosystems.

6.5 Future Directions in Mycorrhizal Carbon Farming

Mycorrhizal fungi would be a strong entry point for integrated carbon farming because of the strength of this means of mitigation for climate change. Future research directions include optimizing fungal strain variants for carbon sequestration, efficacy inoculation strategies, and long-term impacts for soil health and ecosystem resilience in mycorrhizal carbon farming (Field et al., 2016). Through the facilitation of interaction among agricultural practitioners, forest managers, and researchers, mycorrhizal fungi can be at the backbone of resilient, carbon-sequestering managed ecosystems.

7. MYCORRHIZAL FUNGI AND THEIR ROLE IN CLIMATE CHANGE MITIGATION

Mycorrhizal fungi are becoming important agents in climate change mitigation, primarily through their role in the carbon sequestration processes in terrestrial ecosystems. The fungi have been known to enter into mutualistic relationships with the roots of plants whereby they enhance nutrient and water uptake for the plant in exchange for carbon from photosynthesis. Mycorrhizal fungi assist in enhancing plant growth and further enhance the storage of soil carbon, thus providing a critical means of carbon sequestration that can balance atmospheric CO_2 levels (Lehmann et al., 2015; Wilson et al., 2009).

7.1 Mechanisms of Mycorrhizal Fungi in Carbon Sequestration

Mycorrhizal fungi enhance carbon sequestration through direct and indirect means. Directly, it uptakes and stores carbon in soil by transferring photosynthetically derived carbon from host plants into the soil matrix contributing to soil organic matter (Clemmensen et al., 2013). Indirectly, mycorrhizal fungi improve plant productivity, thereby increasing the overall biomass and root exudation rates leading to more carbon inputs into the soil (Treseder, 2004). In addition to this, their mycelial networks stabilize the structure of the soil thus reducing soil erosion and organic matter loss in the soil (Rillig et al., 2001).

7.2 Role in Reducing Greenhouse Gas Emissions

Mycorrhizal fungi have a role beyond carbon sequestration. This mycorrhizal fungus is involved in reducing the emission of greenhouse gases due to decreased use of synthetic fertilizers. It aids in increasing the uptake of nitrogen and phosphorus by the host, thus reducing the use of synthetic fertilizers by the host plants (Smith & Read, 2008). Less fertilizer usage releases less nitrous oxide, a strong greenhouse gas; therefore, there is still more reduction in emissions to maintain climate change mitigation (Hijri, 2016). Further, through the process of mycorrhizal fungi that involves carbon sequestration in soil, it may minimize the efflux of carbon from the soil into the atmosphere by suppressing processes that feed previously stored carbon back into the atmosphere through microbial decomposition and land-use change (Verbruggen et al., 2010).

7.3 Importance of Mycorrhizal Diversity for Climate Resilience

Mycorrhizal fungi have played a very prominent role in their ability to make ecosystems resilient under climate change. Mycorrhizal species are generally diversified, and different types have unique functional traits that enable them to function well under variable environmental conditions such as drought and elevated levels of CO_2 (Bender et al., 2014). Functional diversity increases ecosystem resilience, which means keeping the ability of ecosystems to sequester carbon and maintain productivity in the face of climatic changes (Averill et al., 2014). For instance, arbuscular mycorrhizal (AM) fungi are more dominant in warmer climates and in croplands, whereas ectomycorrhizal (EM) fungi dominate in cooler regions with forests. Such a distribution is a significant factor in maximizing carbon sequestration potential in diverse ecosystems (Brundrett & Tedersoo, 2018).

7.4 Mycorrhizal Fungi in Climate Policy and Carbon Markets

Mycorrhizal fungi are getting increasing attention in climate policy and carbon markets. Their inclusion in soil management practice may enhance the carbon sequestration potential of managed lands and contribute to the achievement of climate targets (Field et al., 2016). One would also view increased interest in the use of mycorrhizal inoculants to agricultural and reforestation sites for the purposes of maximizing carbon capture given that, nowadays, many climate policies incorporate soil carbon sequestration into carbon offset strategy schemes.

7.5 Future Research and Implications for Climate Change Mitigation

Future research should focus on mycorrhizal applications on optimizing climate change mitigation. This includes identifying mycorrhizal strains with high carbon-sequestering potential, characterizing how such fungi interact with other soil microorganisms under climate stressors, and carrying out long-term studies on the application of mycorrhizal in diverse ecosystems (Hartmann et al., 2015). Mycorrhizal fungi across the world's biomes would deliver their potential to support global carbon cycles and climate resilience.

Mycorrhizal fungi represent a viable means of overcoming climate change as they promote carbon sequestration in addition to lowering greenhouse gas emissions. Their inputs in the enhancement of ecosystem resilience and good health of soils and soil-based sustainable land management make them indispensable allies to overcome challenges related to climate change.

8. CONCLUSION

Mycorrhizal fungi are also believed to play an important role in carbon sequestration, with considerable potential in their own right as a natural means for climate change mitigation. The carbon derived by photosynthesis into roots from plants can enter soil and, as such, becomes part of soil organic matter, improving its structure and stabilizing carbon stores (Smith & Read, 2010; Cheng et al., 2012). Among these, ectomycorrhizal (EM) and arbuscular mycorrhizal (AM) fungi are of major importance in their respective functions in reshaping carbon flow throughout ecosystems. Ectomycorrhizal fungi are the most abundant fungal group in temperate and boreal forests and exert a significant impact on the long-term storage of carbon in soils due to their impact on soil carbon pools. Arbuscular mycorrhizal fungi increase soil fertility and allow plants to better tolerate a broad range of ecological conditions (Clemmensen et al., 2013; Averill et al., 2014).

This review describes the mechanisms with which mycorrhizal fungi sequester carbon, such as direct carbon transfer, soil aggregation, and nutrient cycling, which can all be influenced by environmental factors like composition of the soil, climate, and human land use (Treseder, 2016). However, in addition to the carbon-sequestration potential that mycorrhizal fungi posses, environmental alterations due to deforestation, soil destruction, and climatic conditions also affect the mycorrhizal carbon-sequestering stability and storage capacities. Temporal alteration and shift in temperature and rainfall might modify the structures of mycorrhizal communities and may affect carbon sequestration ability negatively. Therefore, understanding the adaptive capacity and resilience of mycorrhizal communities to these changes will help in envisioning their role as a carbon sink in forthcoming climate scenarios.

Mycorrhizal fungi application in managed ecosystems such as agriculture and reforestation provides some of the most promising avenues for carbon farming and sustainable land management. Mycorrhizal inoculation strategies could be executed to support agroforestry practices and incorporate mycorrhizal symbioses into carbon credit markets, as proposed recently, which should enhance carbon sequestration while supporting ecosystem health and biodiversity (Smith & Smith, 2011; Field et al., 2020). Such intricate interactions between mycorrhizae and plants with the soil environment need to be further studied so applications can be developed and possible long-term effects on carbon dynamics can be understood.

Future studies will include quantification of carbon sequestration potential by different types of mycorrhizae across ecosystems, resilience of mycorrhizal networks to variability in climate, and development of strategies for incorporating mycorrhizal fungi into climate policies. Further interdisciplinary research can unlock the potential for carbon sequestration properties of mycorrhizal fungi as an integral component of global strategies to mitigate climate change, thus ensuring a sustainable approach to the management of carbon stocks and soil health.

REFERENCES

1. Allen, M. F. (2007). Mycorrhizal fungi: Highways for water and nutrients in arid soils. *Vadose Zone Journal*, 6(2), 291-297. https://doi.org/10.2136/vzj2006.0068
2. Averill, C., Turner, B. L., & Finzi, A. C. (2014). Mycorrhiza-mediated competition between plants and decomposers drives soil carbon storage. *Nature*, 505(7484), 543–545. https://doi.org/10.1038/nature12901
3. Bahram, M., Hildebrand, F., Forslund, S. K., Anderson, J. L., Soudzilovskaia, N. A., Bodegom, P. M., & Bengtsson-Palme, J. (2018). Structure and function of the global topsoil microbiome. *Nature*, 560(7717), 233–237. https://doi.org/10.1038/s41586-018-0386-6
4. Bardgett, R. D., & van der Putten, W. H. (2014). Belowground biodiversity and ecosystem functioning. *Nature*, 515(7528), 505–511. https://doi.org/10.1038/nature13855
5. Bender, S. F., Wagg, C., & van der Heijden, M. G. (2015). An underground revolution: Biodiversity and soil ecological engineering for agricultural sustainability. *Trends in Ecology & Evolution*, 30(7), 440–452. https://doi.org/10.1016/j.tree.2015.05.004

6. Brundrett, M. C. (2009). Mycorrhizal associations and other means of nutrition of vascular plants: Understanding the global diversity of host plants by resolving conflicting information and developing reliable means of diagnosis. *Plant and Soil*, 320(1), 37–77. https://doi.org/10.1007/s11104-008-9877-9
7. Brundrett, M. C., & Tedersoo, L. (2018). Evolutionary history of mycorrhizal symbioses and global host plant diversity. *New Phytologist*, 220(4), 1108–1115. https://doi.org/10.1111/nph.14976
8. Brunner, I., et al. (2019). Trees for the future: Trees in changing climates. *New Phytologist*, 222(1), 149-161. https://doi.org/10.1111/nph.15599
9. Cheng, X., Luo, Y., Su, B., Verburg, P. S., & Arnone III, J. A. (2012). Responses of soil organic carbon to nitrogen fertilization in a grassland ecosystem. *Plant and Soil*, 355(1), 393–404. https://doi.org/10.1007/s11104-011-1110-2
10. Clemmensen, K. E., Bahr, A., Ovaskainen, O., Dahlberg, A., Ekblad, A., Wallander, H., … & Lindahl, B. D. (2013). Roots and associated fungi drive long-term carbon sequestration in boreal forest. *Science*, 339(6127), 1615–1618. https://doi.org/10.1126/science.1231923
11. Clemmensen, K. E., Finlay, R. D., Dahlberg, A., Stenlid, J., Wardle, D. A., & Lindahl, B. D. (2013). Carbon sequestration is related to mycorrhizal fungal community shifts during long-term succession in boreal forests. *Science*, 339(6127), 1615–1618. https://doi.org/10.1126/science.1231923
12. Dwivedi S., Singh B., Singh A.K. and Singh V.K. (2024a). Preparation of *Pleurotus* spawn on different grain substrates. *International Journal of Biological Innovations*, 6(1), 39-43. https://doi.org/10.46505/IJBI.2024.6105.
13. Dwivedi S., Singh B., Singh A.K. and Singh V.K. (2024b). Cultivation of Oyster Mushroom (*Pleurotus djamor*) by Using Different Substrates in Laboratory Conditions. *KAVAKA*, 60(3), 1-6.
14. Fernandez, C. W., & Kennedy, P. G. (2016). Revisiting the 'Gadgil effect': Do interguild fungal interactions control carbon cycling in forest soils? *New Phytologist*, 209(4), 1382–1394. https://doi.org/10.1111/nph.13648
15. Field, C. B., et al. (2016). The role of soil carbon in carbon markets: Barriers and opportunities. *Global Change Biology*, 22(3), 1317–1329. https://doi.org/10.1111/gcb.13155
16. Field, C. B., Van Noort, S., & Powell, J. R. (2020). Agroforestry: A sustainable solution for nutrient management and carbon sequestration. *Current Opinion in Environmental Sustainability*, 43, 1–9. https://doi.org/10.1016/j.cosust.2020.03.001
17. Field, K. J., Pressel, S., Duckett, J. G., Rimington, W. R., & Bidartondo, M. I. (2019). Symbiotic options for the conquest of land. *Trends in Ecology & Evolution*, 34(4), 320-332. https://doi.org/10.1016/j.tree.2018.12.010
18. Hartmann, M., et al. (2015). Resistance and resilience of the forest soil microbiome to logging-associated compaction. *ISME Journal*, 9(9), 2261–2271. https://doi.org/10.1038/ismej.2015.82
19. Hijri, M. (2016). Analysis of mycorrhizal inoculants used in agriculture, a first step toward quality control. *PLOS ONE*, 11(3), e0150066. https://doi.org/10.1371/journal.pone.0150066
20. Jo, I., Potter, K. M., Domke, G. M., & Fei, S. (2019). Dominant forest tree mycorrhizal associations predict carbon storage in soils. *Ecology Letters*, 22(5), 987–996. https://doi.org/10.1111/ele.13250
21. Johnson, N. C., Graham, J. H., & Smith, F. A. (2013). Functioning of mycorrhizal associations along the mutualism–parasitism continuum. *New Phytologist*, 135(3), 575–585. https://doi.org/10.1111/j.1469-8137.2012.04485.x
22. Johnson, N. C., Wilson, G. W. T., Bowker, M. A., Wilson, J. A., & Miller, R. M. (2017). Mycorrhizal phenotypes and the law of the minimum. *New Phytologist*, 205(4), 1473–1484. https://doi.org/10.1111/nph.13265

23. Lehmann, A., & Rillig, M. C. (2015). Arbuscular mycorrhizal contribution to copper, manganese, and iron nutrient concentrations in crops—A meta-analysis. *Soil Biology and Biochemistry*, 81, 147–158. https://doi.org/10.1016/j.soilbio.2014.11.012
24. Phillips, R. P., Brzostek, E., & Midgley, M. G. (2013). The mycorrhizal-associated nutrient economy: A new framework for predicting carbon-nutrient couplings in forests. *New Phytologist*, 199(1), 41–51. https://doi.org/10.1111/nph.12221
25. Rillig, M. C. (2004). Arbuscular mycorrhizae and terrestrial ecosystem processes. *Ecology Letters*, 7(8), 740–754. https://doi.org/10.1111/j.1461-0248.2004.00620.x
26. Rillig, M. C., & Mummey, D. L. (2006). Mycorrhizas and soil structure. *New Phytologist*, 171(1), 41–53. https://doi.org/10.1111/j.1469-8137.2006.01750.x
27. Rillig, M. C., Wright, S. F., Nichols, K. A., Schmidt, W. F., & Torn, M. S. (2001). Large contribution of arbuscular mycorrhizal fungi to soil carbon pools in tropical forest soils. *Plant and Soil*, 233(2), 167–177. https://doi.org/10.1023/A:1010382702577
28. Rillig, M. C., Wright, S. F., Shaw, M. R., & Field, C. B. (2001). Artificial climate warming positively affects arbuscular mycorrhizae but decreases soil aggregate water stability in an annual grassland. *Oikos*, 94(1), 130–136. https://doi.org/10.1034/j.1600-0706.2001.10310.x
29. Singh, B., Singh, V. K., (2022). Macrofungal (Mushroom) Diversity of Uttar Pradesh, India. *International Research Journal of Modernization in Engineering Technology and Science*, 4(8), 208-217.
30. Singh, B., Singh, V. K., (2023a). Nutritional analysis of some wild collected macrofungi from Ayodhya, Uttar Pradesh, India. *Int. J. Curr. Res. Biosci. Plant Biol.,* 10(6), 1-6. https://doi.org/10.20546/ijcrbp.2023.1006.001
31. Singh, B., Singh, V. K., (2023b). Diversity of Wood-Inhabiting Macrofungi from District Ayodhya, Uttar Pradesh, India. *KAVAKA*, 59(3), 51-61. https://doi.org/10.36460/Kavaka/59/3/2023/51-61
32. Singh, B., Singh, V. K., Kumar, S. (2024). A Survey of Macrofungal Diversity in the Ayodhya Region, Uttar Pradesh, India. *KAVAKA 60(1): 21-31*. https://doi.org/10.36460/Kavaka/60/1/2024/21-31
33. Smith, F. A., & Smith, S. E. (2011). How useful is the mutualism-parasitism continuum of arbuscular mycorrhizal functioning? *Plant and Soil*, 333(1), 47–55. https://doi.org/10.1007/s11104-010-0328-0
34. Smith, S. E., & Read, D. J. (2008). *Mycorrhizal Symbiosis* (3rd ed.). Academic Press.
35. Steidinger, B. S., et al. (2019). Climatic controls of decomposition drive the global biogeography of forest-tree symbioses. *Nature*, 569(7756), 404–408. https://doi.org/10.1038/s41586-019-1128-0
36. Terrer, C., Vicca, S., Hungate, B. A., Phillips, R. P., & Prentice, I. C. (2016). Mycorrhizal association as a primary control of the CO2 fertilization effect. *Science*, 353(6294), 72–74. https://doi.org/10.1126/science.aaf4610
37. Treseder, K. K. (2004). A meta-analysis of mycorrhizal responses to nitrogen, phosphorus, and atmospheric CO2 in field studies. *New Phytologist*, 164(2), 347–355. https://doi.org/10.1111/j.1469-8137.2004.01159.x
38. Treseder, K. K. (2016). The extent of mycorrhizal colonization across soils: Phosphorus and nitrogen as controls. *Global Ecology and Biogeography*, 7(3), 123–137. https://doi.org/10.1007/s10980-015-0315-8
39. Treseder, K. K., & Allen, M. F. (2000). Mycorrhizal fungi have a potential role in soil carbon storage. *Ecology Letters*, 3(3), 131–135. https://doi.org/10.1046/j.1461-0248.2000.00120.x
40. Treseder, K. K., & Holden, S. R. (2013). Climate change and mycorrhizal fungi. *Global Change Biology*, 19(8), 2543–2554. https://doi.org/10.1111/gcb.12208
41. Treseder, K. K., & Turner, K. M. (2007). Glomalin in ecosystems. *Soil Science Society of America Journal*, 71(5), 1257–1266. https://doi.org/10.2136/sssaj2006.0377
42. van der Heijden, M. G., et al. (2015). Mycorrhizal ecology and evolution: The past, the present, and the future. *New Phytologist*, 205(4), 1406–1423. https://doi.org/10.1111/nph.13288

43. Verbruggen, E., & Kiers, E. T. (2010). Evolutionary ecology of mycorrhizal functional diversity in agricultural systems. *Evolutionary Applications*, 3(5-6), 547–560. https://doi.org/10.1111/j.1752-4571.2010.00145.x
44. Wilson, G. W., et al. (2009). Plant species richness, arbuscular mycorrhizal fungal abundance, and ecosystem functioning: Scale-dependent relationships in a multisite grassland study. *Journal of Ecology*, 97(4), 667–678. https://doi.org/10.1111/j.1365-2745.2009.01515.x

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