ROLE OF MYCORRHIZAL FUNGI IN CARBON SEQUESTRATION AND CLIMATE CHANGE MITIGATION: A SYSTEMATIC REVIEW

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ABSTRACT
Climate change is one of the most significant environmental challenges caused by increasing atmospheric greenhouse gas concentrations, particularly carbon dioxide (CO_2). Soil ecosystems represent a major global carbon reservoir, and microbial communities play a vital role in regulating carbon cycling. Among soil microorganisms, mycorrhizal fungi have gained considerable attention due to their ability to enhance carbon sequestration through plant–fungus symbiosis. Mycorrhizal associations improve plant growth, nutrient acquisition, soil aggregation, and carbon stabilization. This systematic review evaluates the contribution of arbuscular mycorrhizal fungi (AMF), ectomycorrhizal fungi (ECM), and other mycorrhizal groups in carbon capture and climate change mitigation. The mechanisms involved include transfer of photosynthetically fixed carbon into fungal biomass, formation of stable soil organic carbon pools, production of glomalin-related soil proteins, and improvement of soil structure. The review also discusses applications, limitations, and future prospects of mycorrhizal biotechnology in sustainable agriculture, forestry, and ecosystem restoration.

KEYWORDS: Mycorrhizal fungi, carbon sequestration, climate change mitigation, soil organic carbon, glomalin, arbuscular mycorrhiza, sustainable agriculture

1. INTRODUCTION

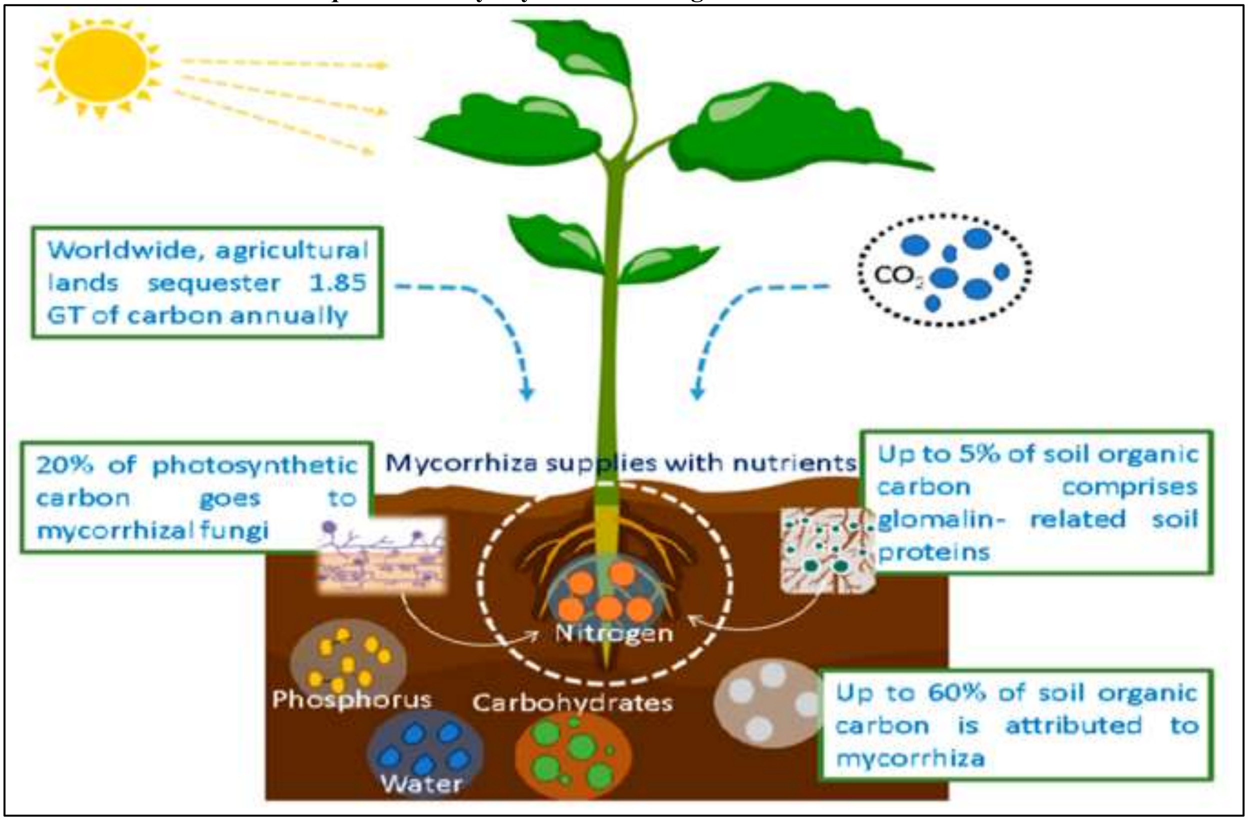
The rise in atmospheric greenhouse gases has accelerated global warming and climate instability. Carbon dioxide emissions from fossil fuel consumption, land-use changes, and intensive agriculture are major contributors to climate change. Soil has the capacity to store large amounts of carbon, making soil carbon sequestration an important natural climate solution.

Mycorrhizal fungi form mutualistic associations with plant roots, facilitating nutrient exchange where fungi receive plant-derived carbon compounds and provide minerals and water to host plants. These fungal networks contribute to carbon storage by incorporating plant carbon into underground biomass and stable soil organic matter. Recent studies show that arbuscular mycorrhizal fungi (AMF) enhance soil carbon sequestration through hyphal networks and improved soil aggregation.

2. Types of Mycorrhizal Fungi Involved in Carbon Cycling

Type	Major Features	Carbon Sequestration Role
Arbuscular Mycorrhizal Fungi (AMF)	Symbiosis with most agricultural plants	Enhances soil carbon storage through hyphae and glomalin
Ectomycorrhizal Fungi (ECM)	Common in forest trees	Increases long-term carbon retention in forest soils
Ericoid Mycorrhiza	Associated with acidic soils	Supports carbon cycling in nutrient-poor ecosystems
Orchid Mycorrhiza	Essential for orchid growth	Contributes to ecosystem carbon balance

3. Mechanisms of Carbon Sequestration by Mycorrhizal Fungi

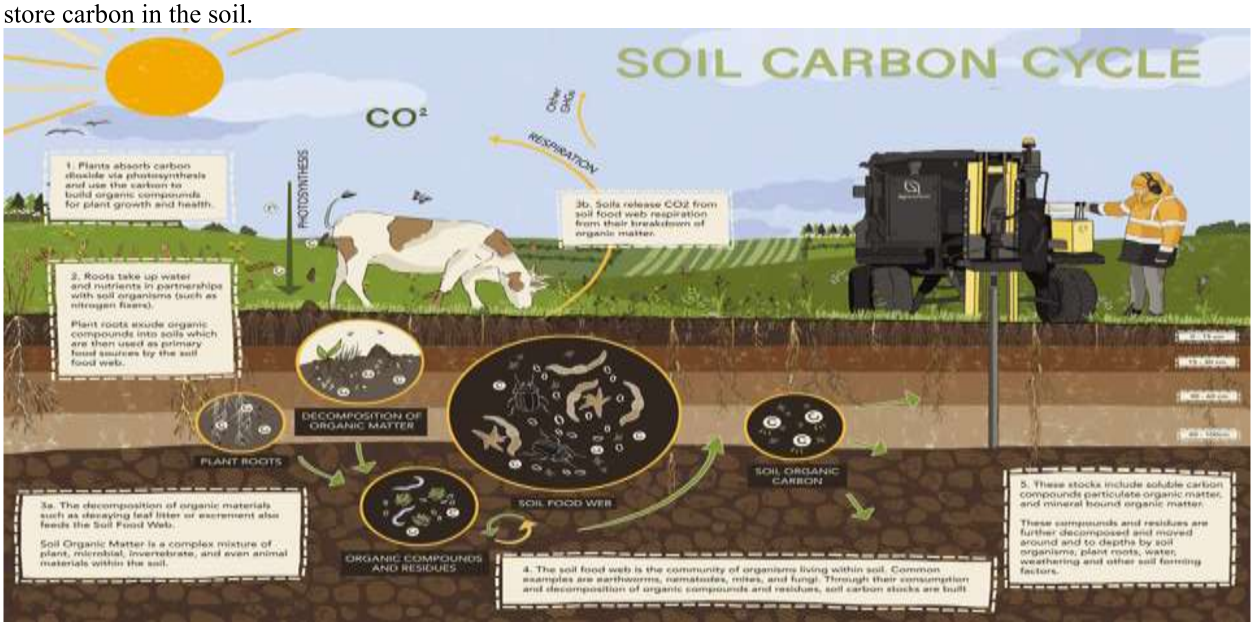


3.1 Transfer of Plant Carbon into Soil

During photosynthesis, plants fix atmospheric CO_2 into carbohydrates. A significant proportion of these carbon compounds is transferred to mycorrhizal fungi through roots. Fungal hyphae distribute carbon into deeper soil layers where it may remain protected from decomposition. This can be known as the Soil Carbon Cycle.

The Soil Carbon Cycle: A Deeper Look

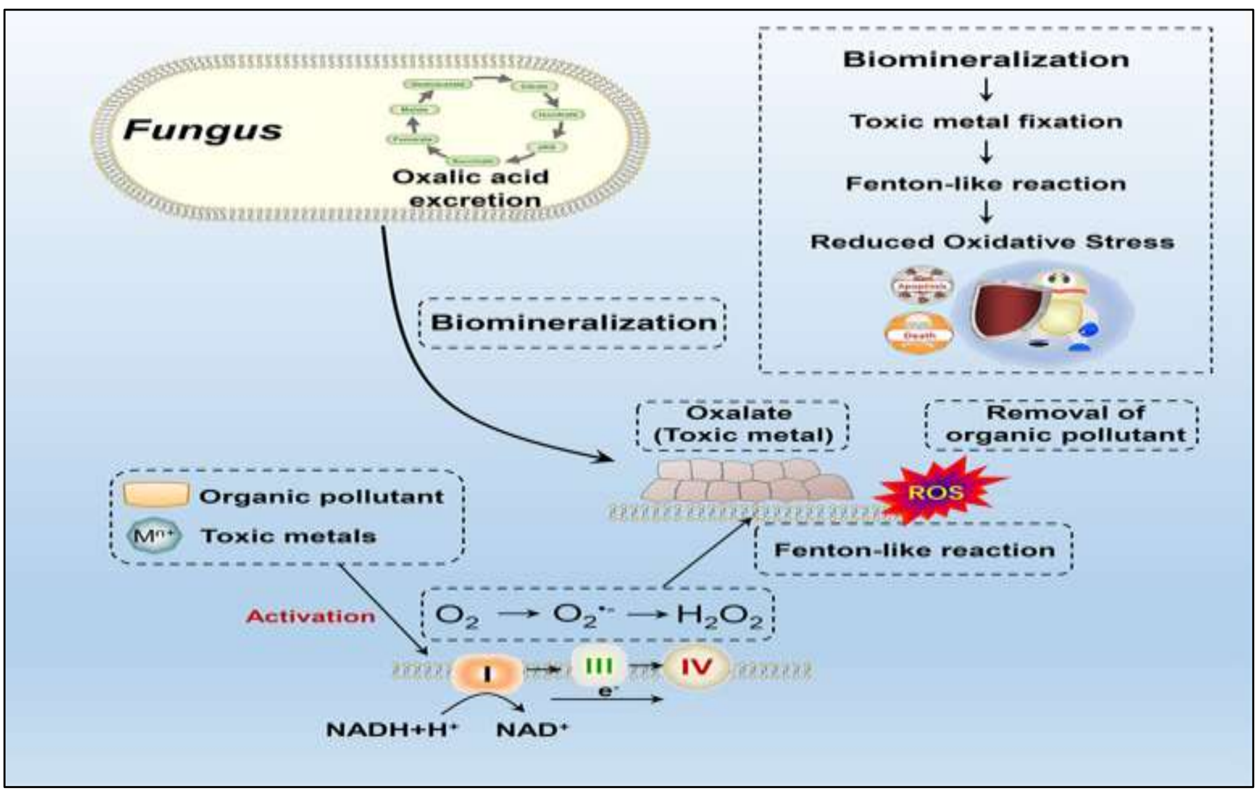
An awareness of the soil carbon cycle's components is required for both climate change mitigation and enabling sustainable agriculture. This cycle involves a series of natural processes that work in harmony to absorb, convert, and store carbon in the soil.



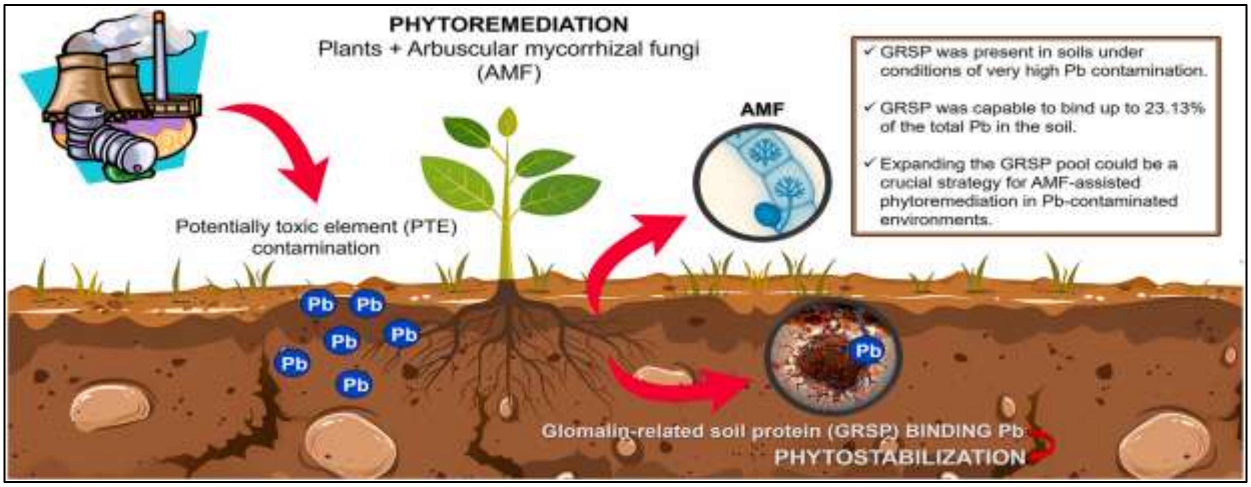
Components of the Soil Carbon Cycle

• **Photosynthesis**
Plants are the primary agents that absorb atmospheric CO_2 and convert it into organic compounds. This process is not just limited to the above-ground parts of plants but also has a significant impact on soil carbon levels.
• **Root Exudation**
Plants transfer carbon to the soil by releasing a variety of organic compounds from their roots. This process is part of a larger system known as the Soil Food Web. Root exudation is crucial for soil health as it provides essential nutrients and helps in carbon sequestration.
• **Decomposition**
Additionally, the Soil Food Web plays a vital role in breaking down organic matter. Microorganisms and other soil organisms decompose organic matter into simpler compounds, enriching the soil with carbon in the process.
• **Soil Food Web**
The Soil Food Web is a complex network of organisms that contribute to the decomposition process. These organisms release vital nutrients and carbon into the soil, enhancing soil health and fertility. Understanding the importance of the Soil Food Web is essential for effective soil carbon management.
• **Soil Respiration**
This process releases CO_2 from the soil primarily through microbial activity and root respiration. However, a conscious balance between carbon input and output ensures that the soil acts as a net carbon sink.
• **Stabilization of Soil Carbon**
The final step in the soil carbon cycle involves transforming carbon compounds into stable forms that resist decomposition. This enables long-term carbon storage in the soil, a critical aspect of mitigating climate change.
Co-Benefits of the Soil Carbon Cycle
Beyond its role in carbon sequestration, the soil carbon cycle provides co-benefits like improved soil health, biodiversity, and water retention. These benefits are not just environmental but also offer massive economic advantages.

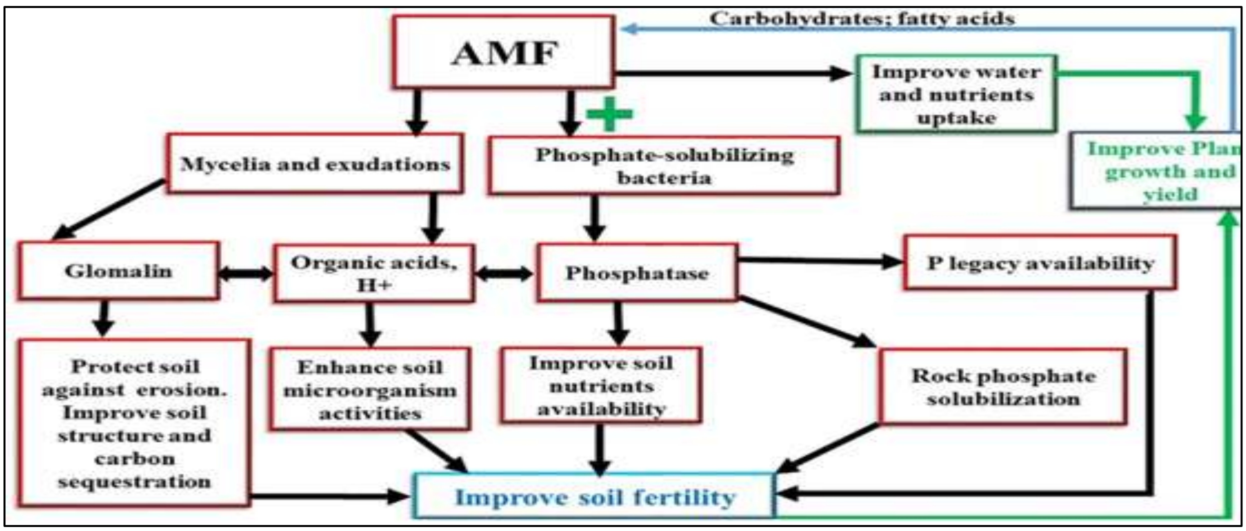
3.2 Fungal Biomass Accumulation
Mycorrhizal hyphae contribute directly to soil organic carbon pools. Dead fungal tissues become part of stable organic matter, increasing carbon residence time.



3.3 Production of Glomalin-Related Soil Proteins
AM fungi produce glomalin-related soil proteins (GRSP), which bind soil particles and enhance aggregate stability. Stable soil aggregates physically protect organic carbon from microbial decomposition.



3.4 Improvement of Soil Structure



The Major Mechanisms Involved in Improving Soil Quality

Mycorrhizae are capable of improving soil quality. They do this by building the soil structure. The mechanisms involved in accomplishing this are:

- Biological
- Biochemical
- Biophysical

1. Biological mechanism

Biologically speaking, depositing mycelium and exudates in the soil help to increase microbial biomass and is also a substrate for the growth of bacteria.

2. Biochemical mechanism

Mycorrhizal hyphae secrete a biological glue known as glomalin to help with the aggregation of soil particles and water stability.

The compounds in the microbial soil biomass help to strengthen the attachment of soil particles. They also help to reduce water tension.

3. Biophysical mechanism

Mycorrhizal hyphae also serve as a tunneling machine. They exert a considerable amount of pressure on the soil particles, forcing clay particles to mix with organic material. This leads to the formation of a micro aggregate.

Creating these tunnels will increase the penetration and movement of both air and water.

Also, mycorrhizal fungi promote wet-dry cycles to increase the binding of fungal exudates, roots, and clay particles. They also entangle and un-mesh s0il particles, small aggregates, and organic matter. This combination helps to improve macro-aggregate formation.

Mycorrhizal networks improve:

Soil porosity
Water retention
Aggregate formation
Resistance to erosion
These properties enhance long-term carbon storage.

4. Role in Climate Change Mitigation
Mycorrhizal fungi contribute to climate mitigation by:

4.1 Increasing Soil Carbon Stocks
Fungal activity promotes movement of atmospheric carbon into below-ground reservoirs.

4.2 Reducing Greenhouse Gas Emissions
Improved nutrient cycling reduces excessive fertilizer use and may decrease agricultural emissions.

4.3 Enhancing Plant Climate Resilience
Mycorrhizal plants show improved tolerance to:

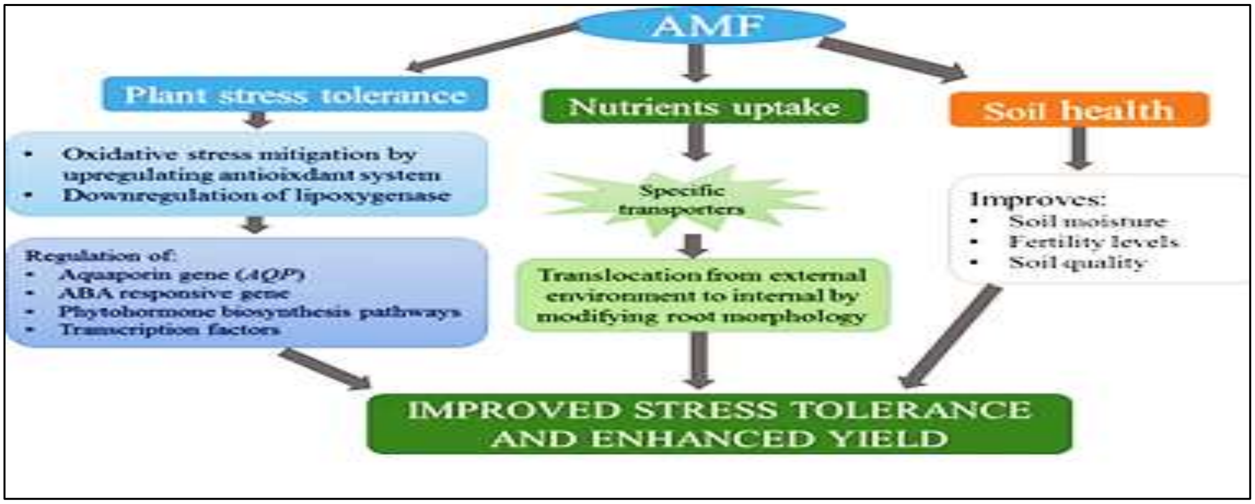
Drought
Heat stress
Soil degradation
Nutrient deficiency

5. Applications

Sector	**Application**
Agriculture	Biofertilizer use and sustainable crop production
Forestry	Forest restoration and carbon farming
Land Reclamation	Recovery of degraded soils
Climate Programs	Nature-based carbon sequestration strategies

6. Challenges and Limitations
Despite their importance, several challenges remain:
1. Variation among fungal species and ecosystems
2. Difficulty in measuring long-term carbon storage
3. Effects of climate change on fungal communities
4. Impact of pesticides and intensive tillage
5. Need for large-scale field validation
Agricultural practices such as intensive tillage can disrupt fungal networks and reduce their contribution to soil carbon storage.

7. Future Perspectives
Future research should focus on:
Development of mycorrhizal-based climate-smart agriculture Molecular understanding of carbon transfer pathways Use of fungal inoculants in degraded ecosystems Integration of mycorrhizal fungi into carbon accounting models



Conservation of underground fungal biodiversity

8. CONCLUSION

Mycorrhizal fungi represent a natural and sustainable pathway for carbon sequestration and climate change mitigation. Through plant–fungus interactions, fungal biomass formation, glomalin production, and soil stabilization, these organisms enhance carbon retention in terrestrial ecosystems. Incorporating mycorrhizal management strategies into agriculture, forestry, and ecosystem restoration can support global climate mitigation efforts.

REFERENCES

1. Shukla S., Didwania N., Choudhary R. (2025). Arbuscular Mycorrhizal Fungi: A pathway to sustainable soil health, carbon sequestration, and greenhouse gas mitigation. Journal of the Saudi Society of Agricultural Sciences.
2. Tao J., Liu X. (2024). Does arbuscular mycorrhizal fungi inoculation influence soil carbon sequestration? Biology and Fertility of Soils.
3. Treseder K.K., Allen M.F. (2000). Mycorrhizal fungi have a potential role in soil carbon storage under elevated CO_2 and nitrogen deposition. New Phytologist.
4. Chahal, K., Gupta, V., Verma, N.K., Chaurasia, A. and Rana, B., 2020. Arbuscular Mycorrhizal (AM) Fungi as a Tool for Sustainable Agricultural System. In Mycorrhizal Fungi-Utilization in Agriculture and Industry. IntechOpen.
5. Chahal, K., Rana, B. & Jha, M., 2022. Arbuscular Mycorrhizal Fungi: A Potentially Sustainable Alternative in Agriculture and Other Ecosystems. Strad Research, 9(7).
6. Review on glomalin-related soil proteins and carbon sequestration. Science of the Total Environment.