International Journal of Engineering and Science Invention (IJESI)
ISSN (Online): 2319-6734, ISSN (Print): 2319-6726
www.ijesi.org ||Volume 8 Issue 7 July 2019 || PP 108-113

Mycorrhizal Fungi: The Underground Internet

Dr. Mahesh Babu
Department of Botany, Govt. P.G. College, Bisalpur Pilibhit

Abstract
Beneath every forest floor, meadow, and garden lies a vast, invisible network that has been quietly operating for hundreds of millions of years. Mycorrhizal fungi form symbiotic associations with the roots of roughly 90% of all land plant species, creating underground webs of fungal filaments called hyphae that connect individual plants across large areas. These networks — sometimes called the "Wood Wide Web" — facilitate the bidirectional transfer of carbon, water, nitrogen, phosphorus, and other nutrients between plants and fungi, and in some cases between different plant individuals. Beyond simple nutrient exchange, emerging evidence suggests these networks play roles in chemical signalling, plant defence responses, and community-level forest dynamics. This article reviews the biology of mycorrhizal associations, the mechanisms by which fungal networks transfer resources and signals, the ecological significance of these connections for forest resilience, and the implications for conservation and agriculture. While scientific enthusiasm about the Wood Wide Web has occasionally outpaced the evidence, the core biology is extraordinary enough on its own terms.

Keywords: *Wood Wide Web, nutrient transfer, forest ecology, mycorrhizal fungi,symbiosis,common mycorrhizal network*

I. Introduction

If you walked into an old-growth forest and looked down, you'd see soil, leaf litter, maybe some mushrooms. What you wouldn't see — what no one saw clearly until the late twentieth century — is a living web of fungal threads connecting the roots of trees around you. Some of those threads are thinner than a human hair. Together, they can stretch for kilometres in a single handful of healthy soil.

Mycorrhizal fungi have been forming partnerships with plants since before trees even existed. Fossil evidence places these associations as far back as 450 million years ago, when the first land plants were colonising barren rock surfaces (Redecker et al., 2000). The relationship they struck up has barely changed since: fungi provide mineral nutrients and water to plant roots, and plants return the favour by feeding fungi sugars produced through photosynthesis. It is, by any measure, one of the most successful biological relationships on Earth.

What makes this story genuinely captivating, though, is the network dimension. Individual fungal threads don't just connect a single fungus to a single plant root. They spread outward, connecting to other roots, other fungi, other plants — sometimes dozens of trees in a single web. Researchers have started calling these structures Common Mycorrhizal Networks (CMNs), and studying them has revealed something that feels almost too strange to be real: trees in a forest are not isolated individuals competing for resources. They are nodes in a network, exchanging carbon, water, and chemical signals through fungal intermediaries.

This article explores what we actually know about these underground systems — the biology, the chemistry, the ecology, and the limits of current understanding. The science is genuinely exciting. It also deserves careful treatment, because popular accounts have sometimes pushed the evidence further than it can comfortably go.

II. The Biology of Mycorrhizal Associations

2.1 What Mycorrhizae Actually Are

The term "mycorrhiza" emerges from the Greek language which uses "mykes" to mean fungus and "rhiza" to mean root. The term defines a particular union that exists between the tissues of fungi and the tissues of plant roots because it shows their complete anatomical connection. The fungus establishes itself on the root system to create a combined organ which operates in a way that differs from the functions of both roots and fungi.

Mycorrhizal associations establish multiple categories, yet two particular types prove most common within terrestrial ecosystems. Arbuscular mycorrhizal (AM) fungi — members of the ancient phylum Glomeromycota — penetrate root cells and form highly branched structures called arbuscules inside the cell wall. The arbuscules serve as the locations where plants exchange nutrients and carbon dioxide, while their branched design enables them to achieve maximum surface area within a confined volume. AM fungi form relationships with most plant families which include agricultural crops, grassland species, and tropical tree species.

Ectomycorrhizal (EM) fungi establish their connection with root cells through an outer wrapping process which creates a protective sheath known as a mantle and a network system that connects nearby cells called the Hartig net. The common species of EM fungi include truffles, boletes, chanterelles, and fly agarics. These fungi establish dominance across temperate and boreal forests which host oak, pine, beech, and birch tree species. Research has focused on these associations because forest networks function at large scales, and the studied tree species serve both ecological and practical purposes.

2.2 The Exchange at the Root

At the cellular level, the mycorrhizal exchange is elegant. Plants shuttle sugars — primarily sucrose — from their leaves down to their roots via the phloem. At the mycorrhizal interface, these sugars are transferred to the fungus. Estimates suggest that between 4% and 20% of the carbon a plant fixes through photosynthesis ends up feeding its mycorrhizal partners (Smith & Read, 2008). That's a significant investment, and it only makes sense if the return is worth it.

The return is minerals — primarily phosphorus and nitrogen, both of which are often in short supply in soils. Fungal hyphae are extraordinarily thin, small enough to penetrate spaces between soil particles that roots cannot access. They also secrete enzymes that break down organic matter, releasing phosphorus and nitrogen that would otherwise remain locked up. The fungus transports these minerals back through its hyphal network to the plant root interface, where they are transferred into root cells. The plant gets minerals it couldn't reach; the fungus gets sugars it can't make for itself.

What makes this exchange remarkable at the network scale is that a single fungal individual can simultaneously connect with many plants. A single gram of forest soil can contain several kilometres of fungal hyphae, and those hyphae can link roots belonging to different trees, different species, even trees separated by tens of metres (Simard et al., 1997).

III. Common Mycorrhizal Networks: The Wood Wide Web

3.1 How Networks Form

The phrase "Wood Wide Web" was coined in a 1997 Nature paper by Suzanne Simard and colleagues, and it caught public imagination immediately. A single fungal organism which spreads its mycelium through multiple plant roots establishes a physical connection between those plants. Fungal hyphae enable carbon and water and nutrients to move between two plants because they serve as a bridge that connects both plants to their soil source.

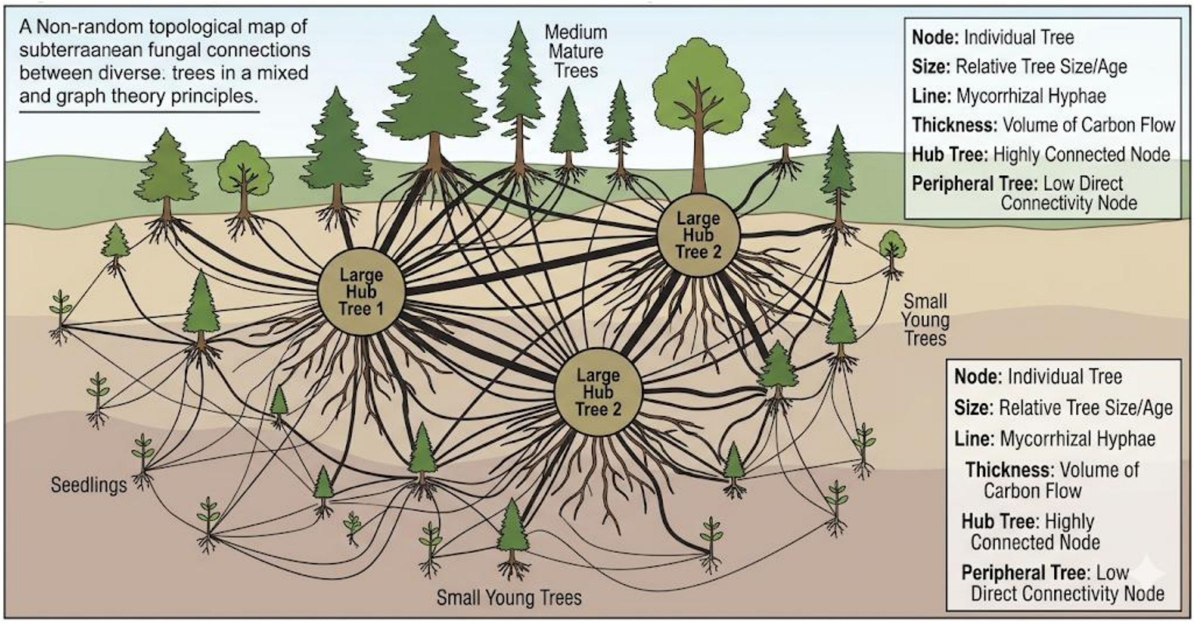

Fig. 1: Conceptual Architecture of a Common Mycorrhizal Network in a Temperate Forest, Source: Author Generated

This diagram shows the hyphal connections between trees of varying ages and sizes in a mixed conifer forest. Large hub trees at the centre of the diagram are connected to many smaller trees via branching fungal threads. Peripheral trees, including seedlings, are shown connected to fewer direct links but remain part of the broader network through intermediate connections. The thickness of connecting lines represents the estimated volume of carbon flow, with thicker lines indicating greater transfer. The key insight is the non-random topology: large trees serve as network hubs rather than all trees connecting equally, suggesting the network has a structure that may concentrate resources toward established individuals.

This hub structure has practical consequences. When Simard's team labelled carbon with radioactive tracers in mature Douglas firs and paper birches, they found carbon moving from one species to the other through shared mycorrhizal networks. The direction of transfer wasn't random — it appeared to follow gradients in carbon availability, so shaded, carbon-stressed seedlings received more carbon from well-lit neighbours than vice versa (Simard et al., 1997).

3.2 What Actually Moves Through These Networks

Scientists study carbon transfer as the primary focus of their research although other substances also move through CMNs. Phosphorus nitrogen and water travel in both directions through fungal hyphae. The research discovered unexpected results when it investigated defencesignalling mechanisms. When insects attack a plant or a pathogen infects it, the plant produces chemical signals that travel through fungal networks to nearby plants which start their defence mechanisms before the pest or pathogen arrives (Song et al., 2010).

IV. Ecological Significance

4.1 Nutrient Cycling in Forest Ecosystems

The mycorrhizal networks inside ecosystems serve a vital role because they control nutrient distribution throughout forest ecosystems. The trees of a forest system extract phosphorus and nitrogen from the ground but they recycle these substances through their body and release them back into the environment through leaf litter while they rely on decomposers and mycorrhizal fungi for their reabsorption. The cycle represents a complete system which involves chemical processes and biological processes while fungi function as its main element.

In soils that have phosphorus shortages which exist across most of the Earth's land area AM fungi enable plants to take up as much as 80 percent of their needed phosphorus (Smith & Read 2008). The plant suffers when you take away the fungi. The situation requires urgent action because agricultural soils which received excessive tilling and synthetic fertiliser applications and monoculture cropping practices now exhibit extreme mycorrhizal population reduction which causes their plants to depend on external nutrients instead of using their native soil resources.

Ectomycorrhizal fungi from boreal and temperate forests function as crucial elements in the process of nitrogen recycling. EM species have the ability to convert organic nitrogen compounds into usable forms without requiring the bacterial decomposition process that ecological models consider standard. The fungal system functions as a nutrient distribution system while it develops nutrients through its competition with bacteria for organic substances and its effect on the decomposition speed (Read & Perez-Moreno 2003).

4.2 Seedling Survival and Forest Regeneration

One of the most practically significant findings in mycorrhizal ecology involves forest regeneration. Seedlings establishing themselves on a forest floor face brutal competition for light, water, and nutrients from established trees. The mycorrhizal network seems to partly buffer that disadvantage.

Simard's group has repeatedly shown that Douglas fir seedlings establishing near mature firs receive carbon subsidies through shared fungal networks — subsidies that appear to improve their survival rates (Simard et al., 2015). The interpretation is that established "mother trees" are effectively subsidising their offspring or nearby kin through the fungal web. This finding has attracted enormous popular attention, inspiring books, documentaries, and Ted Talks, as well as a significant amount of scientific scepticism about methodology and interpretation.

4.3 Interspecies Communication and Forest Community Dynamics

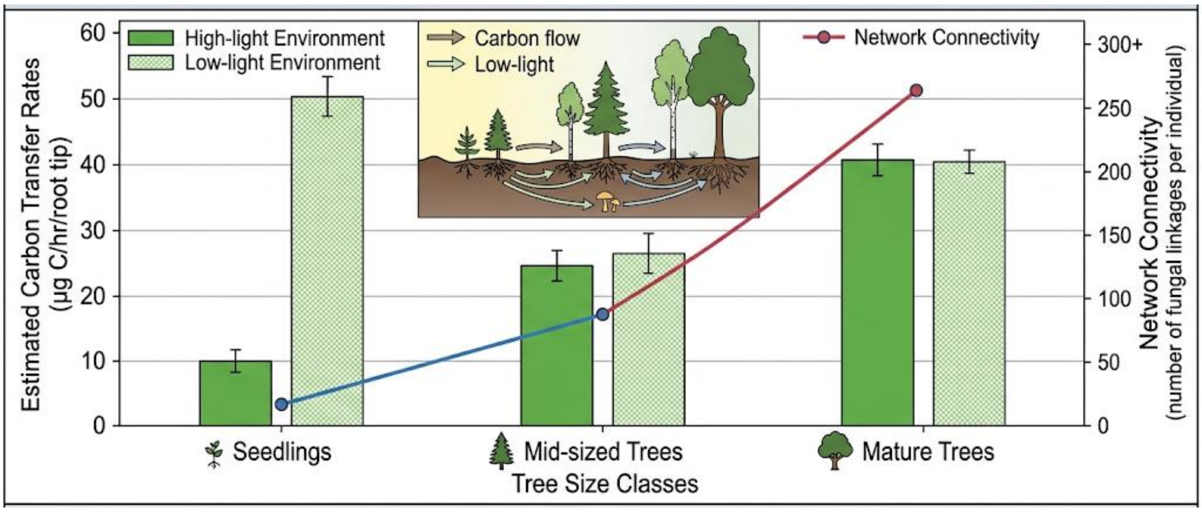

Fig. 2: Carbon Transfer Rates and Network Connectivity by Tree Size Class in Douglas Fir – Paper Birch Mixed Forest, Source: Author Generated

This bar chart compares estimated carbon transfer rates (measured in micrograms of carbon per hour per root tip) across three tree size classes — seedlings, mid-sized trees, and mature trees — under two conditions: high-light and low-light environments. In low-light conditions, seedlings receive significantly more carbon via mycorrhizal networks than in high-light conditions, while mature trees show relatively consistent transfer rates regardless of light availability. The chart also overlays a line graph showing network connectivity (number of fungal linkages per individual), which increases sharply with tree size. The key takeaway is that the mycorrhizal network appears to redistribute carbon toward trees most in need of supplemental carbon income, suggesting a functionally significant resource-equalising effect.

Beyond carbon and nutrients, the mycorrhizal network appears to shape which species can grow where. Ectomycorrhizal fungi are often host-specific or host-preferential, meaning certain fungi form much better partnerships with certain tree species than others. This specificity influences competitive dynamics in forests — tree species that share effective fungal partners can potentially benefit from each other's presence, while tree species that compete for the same fungal networks might suppress each other.

This has implications for how we think about forest diversity. A diverse fungal community may support a diverse plant community, not just because the fungi fill different nutrient-gathering niches, but because the network structure they create mediates interactions between plants in complex ways (van der Heijden et al., 1998). Simplified fungal communities — as often occur in managed forests or disturbed soils — may produce simplified plant communities, with cascading effects on forest resilience.

V. Mycorrhizal Networks and Climate Change

The relationship between mycorrhizal networks and climate is bidirectional, and both directions matter for the future.

Trees store enormous amounts of carbon, and roughly a quarter of all the carbon entering forest soils does so via the mycorrhizal pathway. Carbon that flows from tree roots into fungal tissue enters the soil organic matter pool, where some of it is stabilised for decades or centuries. The mycorrhizal contribution to soil carbon storage is substantial and is increasingly being incorporated into ecosystem carbon models (Averill et al., 2014).

At the same time, climate change stresses plant communities in ways that may compromise mycorrhizal networks. Drought reduces the carbon plants can afford to invest in fungal partners. Temperature shifts alter which fungal species are competitive in a given soil. Changed precipitation patterns affect soil moisture, which fungi are highly sensitive to. There is some evidence that elevated CO2 actually increases mycorrhizal colonisation, as plants produce more carbon and can afford to share more with their fungal partners — but whether increased colonisation translates into increased ecological function is unclear (Treseder, 2004).

The reciprocal nature of the relationship means that a forest under climate stress may find its mycorrhizal networks weakened precisely when it needs them most. Stressed trees invest less in their fungal partners. Weakened networks are less able to buffer nutrient and water stress in those same trees. This feedback loop could accelerate forest decline under changing conditions — a concern that is now motivating research into whether mycorrhizal community composition can be managed to improve forest resilience.

VI. Agricultural Applications

6.1 Rebuilding Depleted Mycorrhizal Communities

Modern agriculture has, largely unintentionally, done enormous damage to mycorrhizal communities in agricultural soils. Tillage physically destroys fungal networks. High phosphorus fertilisation suppresses mycorrhizal colonisation — plants stop investing in fungal partners when soluble phosphorus is abundant. Fungicide applications can decimate fungal communities. Long fallow periods starve fungi of their plant hosts.

The result is agricultural soils with much lower mycorrhizal diversity and activity than neighbouring natural soils. This matters because mycorrhizal fungi don't just move nutrients — they also produce compounds like glomalin that bind soil particles together, improving soil structure, water retention, and erosion resistance. Depleted mycorrhizal communities are one reason why many intensively farmed soils have poor structure and high erosion rates (Rillig, 2004).

Rebuilding mycorrhizal communities in agricultural soils is technically feasible. Reducing tillage intensity, incorporating cover crops that host AM fungi, reducing phosphorus fertiliser inputs, and inoculating transplants with commercial mycorrhizal products can all help. The challenge is that results are highly context-dependent. Commercial mycorrhizal inoculants don't always outperform the native fungal community already present in soil, especially in soils that have retained some fungal diversity (Ryan & Graham, 2002).

6.2 Implications for Sustainable Farming

The potential is actual because it exists. Crops with strong mycorrhizal associations achieve superior phosphorus acquisition which leads to decreased need for fertilizers. The plants use their ability to reach deep soil moisture reserves which helps them withstand drought conditions. Mycorrhizal associations enable certain systems to develop better protection against soil-borne pathogens. The benefits from these methods support effective agronomy practices because they decrease both input expenses and environmental harm.

Some researchers have proposed using mycorrhizal community composition as an indicator of soil health — the idea being that a diverse, active fungal community signals a healthy, functional soil ecosystem. The concept remains feasible however it has not yet developed into dependable agricultural field assessment tools which farmers can apply in their daily work.

VII. Conclusion

Mycorrhizal fungi now function as essential elements that sustain all terrestrial ecosystems. The underground networks they create function as essential systems which support ecosystem operations. The ecosystems we observe today depend on these underground structures because they enable all plants to survive while maintaining forest ecosystems which store carbon and manage water and protect biodiversity through their natural defenses.

Current scientific research develops at an accelerated pace. Molecular tools that can identify fungal species directly from soil DNA have transformed our ability to map network composition and structure. Long-term field experiments are finally starting to generate the kind of data needed to test network-level hypotheses in realistic conditions. Climate change creates unwanted natural experiments which demonstrate how forest ecosystems behave when their mycorrhizal communities experience disruption.

The biology that exists underground our feet exceeds the complexity of surface life because it contains ancient biological systems that have far-reaching impacts. Every tree you've ever stood next to was almost certainly connected to its neighbours through threads you couldn't see. The concept exists as a fundamental truth which must be observed in all fields of research which investigate how Earth sustains its biological systems including conservation and forestry and agriculture and basic scientific research.

References

[1]. 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

[2]. Bago, B., Pfeffer, P. E., & Shachar-Hill, Y. (2000). Carbon metabolism and transport in arbuscular mycorrhizas. *Plant Physiology*, *124*(3), 949–957. https://doi.org/10.1104/pp.124.3.949

[3]. Brundrett, M. C. (2002). Coevolution of roots and mycorrhizas of land plants. *New Phytologist*, *154*(2), 275–304. https://doi.org/10.1046/j.1469-8137.2002.00397.x

[4]. Cornelissen, J. H. C., Aerts, R., Cerabolini, B., Werger, M. J. A., & van der Heijden, M. G. A. (2001). Carbon cycling traits of plant species are linked with mycorrhizal strategy. *Oecologia*, *129*(4), 611–619. https://doi.org/10.1007/s004420100752

[5]. Finlay, R. D. (2008). Ecological aspects of mycorrhizal symbiosis: With special emphasis on the functional diversity of interactions involving the extraradical mycelium. *Journal of Experimental Botany*, *59*(5), 1115–1126. https://doi.org/10.1093/jxb/ern059

[6]. Fitter, A. H., Hodge, A., Daniell, T. J., & Robinson, D. (1999). Resource sharing in plant-fungus communities: Did the carbon move? *Trends in Ecology & Evolution*, *14*(2), 70. https://doi.org/10.1016/S0169-5347(98)01555-8

[7]. Giovannetti, M., Sbrana, C., Avio, L., &Strani, P. (2004). Patterns of below-ground plant interconnections established by means of arbuscular mycorrhizal networks. *New Phytologist*, *164*(1), 175–181. https://doi.org/10.1111/j.1469-8137.2004.01145.x

[8]. Helgason, T., Daniell, T. J., Husband, R., Fitter, A. H., & Young, J. P. W. (1998). Ploughing up the wood-wide web? *Nature*, *394*(6692), 431. https://doi.org/10.1038/28764

[9]. Leake, J. R., Johnson, D., Donnelly, D. P., Muckle, G. E., Boddy, L., & Read, D. J. (2004). Networks of power and influence: The role of mycorrhizal mycelium in controlling plant communities and agroecosystem functioning. *Canadian Journal of Botany*, *82*(8), 1016–1045. https://doi.org/10.1139/b04-060

[10]. Molina, R., Massicotte, H., & Trappe, J. M. (2001). Specificity phenomena in mycorrhizal symbioses: Community ecological consequences and practical implications. In M. F. Allen (Ed.), *Mycorrhizal functioning* (pp. 357–423). Chapman & Hall.

[11]. Read, D. J., & Perez-Moreno, J. (2003). Mycorrhizas and nutrient cycling in ecosystems: A journey towards relevance? *New Phytologist*, *157*(3), 475–492. https://doi.org/10.1046/j.1469-8137.2003.00704.x

[12]. Redecker, D., Kodner, R., & Graham, L. E. (2000). Glomalean fungi from the Ordovician. *Science*, *289*(5486), 1920–1921. https://doi.org/10.1126/science.289.5486.1920

[13]. Rillig, M. C. (2004). Arbuscular mycorrhizae, glomalin, and soil aggregation. *Canadian Journal of Soil Science*, *84*(4), 355–363. https://doi.org/10.4141/S04-003

[14]. Ryan, M. H., & Graham, J. H. (2002). Is there a role for arbuscular mycorrhizal fungi in production agriculture? *Plant and Soil*, *244*(1–2), 263–271. https://doi.org/10.1023/A:1020207631893

[15]. Simard, S. W., Beiler, K. J., Bingham, M. A., Deslippe, J. R., Philip, L. J., & Teste, F. P. (2015). Mycorrhizal networks: Mechanisms, ecology, and modelling. *Fungal Biology Reviews*, *26*(1), 39–60. https://doi.org/10.1016/j.fbr.2012.01.001

[16]. Simard, S. W., Perry, D. A., Jones, M. D., Myrold, D. D., Durall, D. M., & Molina, R. (1997). Net transfer of carbon between ectomycorrhizal tree species in the field. *Nature*, *388*(6642), 579–582. https://doi.org/10.1038/41557

[17]. Smith, S. E., & Read, D. J. (2008). *Mycorrhizal symbiosis* (3rd ed.). Academic Press.

[18]. Song, Y. Y., Zeng, R. S., Xu, J. F., Li, J., Shen, X., &Yihdego, W. G. (2010). Interplant communication of tomato plants through underground common mycorrhizal networks. *PLoS ONE*, *5*(10), e13324. https://doi.org/10.1371/journal.pone.0013324

[19]. 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

[20]. van der Heijden, M. G. A., Klironomos, J. N., Ursic, M., Moutoglis, P., Streitwolf-Engel, R., Boller, T., Wiemken, A., & Sanders, I. R. (1998). Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity. *Nature*, *396*(6706), 69–72. https://doi.org/10.1038/23932