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Cover Photo: Panoramic view of Achanakmar-Amarkantak Biosphere Reserve



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From the Editor's desk

Agroforestry intensification among smallholder farmers in India represents a transformative pathway toward resilient rural livelihoods and sustainable land stewardship. As climate variability intensifies, integrating trees with crops and livestock is increasingly proving to be a buffer against erratic rainfall, soil degradation, and declining farm productivity. Recent assessments indicate that agroforestry can enhance smallholder farm incomes by 20–60% through diversified outputs such as fruits, fodder, fuelwood, and timber, while simultaneously improving soil organic carbon by 15–25% over a decade. The expansion of schemes like the National Agroforestry Policy (2014) and state-led tree promotion initiatives has further catalyzed adoption, yet constraints such as limited market access, slow-growing tree varieties, and credit bottlenecks persist. Strengthening value chains, promoting fast-maturing species, and providing decentralized extension support will be vital to accelerate this transition. Ultimately, intensification of agroforestry is not merely an agronomic upgrade—it is a socio-ecological investment that can uplift millions of smallholders while advancing India's climate mitigation and land restoration commitments.

In line with the above this issue of Van Sangyan contains an article on Agroforestry intensification among smallholder farmers in India. There are also useful articles viz.. Mycosilviculture - An emerging tool in forest management, Pongamia pinnata (L.) Pierre, (पोंगामिया पिन्नाटा) के पत्तों पर गॉल माइट (Aceria pongamiae) का प्रकोप, Production, decomposition, and the role of microbes in litter of Eucalyptus and Casuarina plantations in Telangana, Quercus glauca- an important fodder tree species, Harnessing multipurpose tree species for the bio-remediation and restoration of degraded soils, The amazon rainforest: Importance, threats and conservation strategies, Crepidium acuminatum: Insights into a lesser known medicinal orchid, and conservation and Kalihari (Gloriosa superba L.): An endangered medicinal flame of nature

Looking forward to meet you all through forthcoming issues

Dr. Naseer Mohammad

Chief Editor



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Agroforestry intensification among smallholder farmers in India

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Abstract

Agroforestry is a multifunctional land-use system integrating trees with crops and livestock to enhance ecological resilience, farm productivity, and rural livelihoods. As a nature-based solution, it contributes significantly to climate change mitigation and adaptation by sequestering carbon, improving soil health, conserving biodiversity, and moderating micro-climatic conditions. The system provides essential products such as fruit, fuelwood, fodder, fibre, fertilizer, timber, and various non-timber forest products, thereby strengthening household income and reducing vulnerability among smallholder farmers in India. Globally practiced across nearly one billion hectares, agroforestry is particularly important in India, where it covers about 28.42 million hectares and supports a predominantly smallholder farming community. Despite its ecological and socio-economic benefits, agroforestry intensification is constrained by limited technical knowledge, financial barriers, insecure land tenure, and underdeveloped markets. Strengthening policy implementation, improving credit access, and enhancing capacity-building initiatives are essential for accelerating adoption. Agroforestry's potential to simultaneously increase land productivity, sequester carbon, and support climate-resilient livelihoods underscores its importance in

sustainable agricultural development. Advancing agroforestry intensification through integrated research, policy support, and farmer participation will be crucial for ensuring long-term environmental sustainability and livelihood improvement in India's diverse agro-climatic regions.

Keywords: Agroforestry, Smallholder farmers, Climate resilience, Livelihood income, Sustainability

Introduction

Agroforestry is a multifunctional land-use system that combines trees, agricultural crops and/or livestock to optimize ecological and economic benefits for the welfare of living beings. It also plays a critical role in climate change mitigation and adaptation (van Noordwijk *et al.*, 2023) by sequestering carbon, enhancing biodiversity, environmental services, and improving microclimatic conditions. As a nature-based solution, agroforestry contributes to food security, enhances soil health, purify water and increases farm productivity through the efficient utilization of natural resources. The strategic inclusion of woody perennials within farming systems provides smallholder farmers with essential products such as 5Fs "Fruit, Fuelwood, Fodder, Fibre and Fertilizer", timber as well as non-timber forest products, thereby diversifying income streams and reducing



economic vulnerability (ICFRE, 2020). Moreover, agroforestry has gained significant credit worldwide due to its role in sustainable agricultural intensification, particularly in developing countries where smallholder farmers constitute the majority of the farming population.

Globally, agroforestry systems occupy approximately one billion hectares of land, supporting more than 1.2 billion people who depend on agroforestry products and services (World bank, 2004). In India, agroforestry covers around 28.42 million hectares, accounting for 8.65% of the total geographical area which is the seventh-largest country in the world (Arunachalam *et al.*, 2022). These figures indicate that agroforestry is not only a critical component of global agriculture but also a major land-use strategy in India. India's agrarian economy heavily depends on smallholder farmers, who make up 86.2% of all farmers but own only 47.3% of the arable land (Agricultural Census, 2015-16). This land fragmentation, coupled with

increasing climatic uncertainties, necessitates the adoption of integrated intensive farming approaches like agroforestry to ensure long-term agricultural sustainability. Smallholder farmers face multiple challenges, including soil degradation, declining yields, water scarcity, and economic instability. Therefore, agroforestry intensification offers a viable solution to these worldwide problems by promoting diversified production systems that enhance land productivity as well as livelihood security. The primary goal of agroforestry intensification is to boost agricultural production per unit area while maintaining or enhancing environmental quality as well as rural livelihood. The successful implementation of these practices involves the strategic selection and arrangement of tree species alongside crops and livestock that maximizes ecosystem functionality. Various agroforestry systems have been developed in diverse agro-climatic regions of India as following:

Table 1: Agroforestry systems in India

Agroforestry systems	Description
Agrisilviculture	Widely practiced agroforestry system in India. Integrates crop cultivation with tree management across seven agro-climatic regions.
Agri-horticulture	It integrates fruit trees with crops across six agro-climatic regions.
Agri-silvi-horticulture	It incorporates trees, crops, fruit-bearing trees, across two agro-climatic regions.
Agri-silvi-pasture	Integrates trees, shrubs, and livestock on the same land.
Boundary Plantation	Trees planted around farmland as protective borders.
Alley Cropping	Rows of shrubs or trees separated by wide alleys for crop cultivation.
Silvi-Olericulture	Integrates trees with vegetable cultivation.
Horti-Olericulture	Integrates fruit tree cultivation with vegetable farming
Horti-Pasture	A farming system that combines fruit-bearing trees with



	livestock grazing or pasture.
Homestead Agroforestry	A diverse land-use system that includes various combinations of trees, fruit crops, and vegetables. Specialized systems also exist, such as Jhum (shifting cultivation) in the Eastern Himalayas and traditional home gardens in the East Coast plateau, Western Ghats, and Island regions.

Source: Handa *et al.*, (2015); Sharma *et al.*, (2017)

The role of agroforestry in climate resilience is particularly significant for smallholder farmers in India, who are highly vulnerable to extreme weather events. Agroforestry systems help regulate microclimates, soil fertility, enhance soil water retention, and reduce temperature fluctuations, thereby mitigating the adverse impacts of climate variability. The deep root systems of trees enhance groundwater recharge and prevent soil erosion, making agroforestry a crucial strategy for climate adaptation in India's diverse agro-climatic zones.

The socio-economic and environmental benefits of agroforestry have been a growing policy emphasis on its promotion in India. The National Agroforestry Policy (2014) seeks to enhance co-ordination and integration among different agroforestry components in Indian Agriculture. It focuses on boosting productivity, generating employment, and improving the livelihoods of rural households among small landholder farmers. Additionally, the Sub-Mission on Agroforestry under the National Mission for Sustainable Agriculture also aims to provide financial assistance and technical guidance to farmers adopting agroforestry practices in India.

Scientific basis for agroforestry intensification

Agroforestry intensification is based on ecological principles that promote efficient

resource utilization, resilience, and sustainability. The key scientific processes involved include:

Nutrient cycling and soil fertility enhancement

- Agroforestry systems enhance soil organic matter content, promote nitrogen fixation (e.g., through leguminous trees like *Gliricidia sepium*), and improve microbial activity, leading to increased soil fertility and productivity.
- *Gmelina arboria*, *Michelia oblonga*, *Alnus nepalensis*, *Parkia roxburghii* and *Pinus kesiya* illustrate great potential by boosting soil organic carbon, improving soil aggregation, increasing soil moisture and minimizing soil erosion (Handa *et al.*, 2015).
- Leaf litter decomposition from tree components enriches soil nutrients, reducing the need for synthetic fertilizers and improving soil structure.

Water conservation and microclimate regulation

- Tree components in agroforestry systems improve groundwater recharge, enhance soil moisture retention, and reduce evapotranspiration losses in drought-prone regions.



- Various agroforestry systems viz., agrisilviculture, agrihorticulture and silvipasture serves best as a watershed management component due to its widespread implementation throughout India.
- Agroforestry-based watershed initiatives contribute to ecosystem enhancement by promoting water conservation, ultimately ensuring greater water availability for farmers over time. Agroforestry systems moderate temperature fluctuations, reduce wind velocity, and provide shade which creating favorable microclimatic conditions for crop growth.

Carbon sequestration and climate change mitigation

- Agroforestry is recognized as a climate-smart agricultural approach due to its ability to sequester atmospheric carbon in biomass and soil organic matter.
- Studies have shown that agroforestry systems store significantly more carbon per hectare compared to conventional monoculture systems.
- Agroforestry systems play a significant role in carbon sequestration by storing substantial amounts of carbon in both above-ground and below-ground biomass, as well as in soil. These systems help regulate the carbon cycle and have been found to sequester more carbon across various components compared to conventional plantations which reducing atmospheric greenhouse gas

concentrations (Ajit *et al.*, 2017; Kumar *et al.*, 2021).

- Additionally, studies indicate that agroforestry sequesters approximately 30-45% more carbon in tree biomass than natural forests in the central Himalayan region. Over the next 50 years, agroforestry systems have the potential to mitigate 1.1-2.2 Pg C in terrestrial ecosystems (Albrecht and Kandji, 2003).

Biodiversity conservation and pest management

- Tree-based agricultural landscapes support higher biodiversity levels, providing habitat for pollinators, beneficial insects, and birds that contribute to natural pest control.
- By incorporating trees into existing agricultural landscapes, agroforestry establishes new ecological niches and enhances biodiversity, particularly among birds, insects, and rodents, compared to monoculture systems. These systems typically sustain 50-80% of the biodiversity present in natural ecosystems (Singh *et al.*, 2011).
- Mixed cropping patterns disrupt pest life cycles and reduce the risk of widespread pest infestations compared to monoculture farming.

Economic and social benefits of agroforestry intensification

Agroforestry intensification provides multiple socio-economic benefits that enhance rural livelihoods:

Increased income and employment

Agroforestry plays a crucial role in boosting productivity, income,



employment, and livelihood opportunities, particularly for smallholder farmers in rural areas. In regions like Uttar Pradesh and Bundelkhand, farmers adopt agroforestry mainly for the additional income it generates alongside traditional crops, providing a quick source of cash (Singh *et al.*, 2011). In contrast, in Punjab and Haryana, large landowners grow Poplar and *Eucalyptus* for economic returns, while small and marginal farmers depend on agroforestry for their essential needs, including food, fodder, and overall livelihood security.

Improved livelihoods and income stability

When small landholders implement agroforestry by cultivating crops such as medicinal plants, fruit trees, nuts, and fodder instead of grass, fuelwood, and timber, they experience greater benefits and an improved quality of life (Raj *et al.*, 2019). Agri-silviculture, Agri-horticulture and Agri Horticulture were the most common traditional agroforestry systems which played an important role in accomplishing socioeconomic status and livelihoods in the Indian Garhwal Himalaya. Studies from this region indicate that agroforestry enhances farmer's income, provides convenient access to firewood and timber, contributes to forest conservation, and improves the overall socioeconomic conditions of rural communities.

Enhanced food security

Diversification of farm outputs ensures ongoing supply of food throughout the year reducing the household vulnerability to market fluctuations. For instance, agri-horticulture farms that mainly take up cultivation of fruit crops like mango,

pomegranate, cashew, jackfruit, etc. enhance nutrition and health status of families (Tirakannanavar *et al.*, 2016).

Empowerment of marginalized groups

Agroforestry provides diverse opportunities for smallholder women, offering financial stability through increased access to high-value crops like pineapple, gooseberry and guava which they might not otherwise be able to afford due to the high costs of advanced technologies. Research shows that women's self-help groups have adopted strategies such as home gardens to address household food and nutrition security. Additionally, agroforestry systems generate employment for women and landless laborers by encouraging activities such as nursery management, tree planting, and harvesting.

Challenges and constraints in agroforestry intensification

The widespread implementation of agroforestry intensification faces different challenges presented in Figure 1:

Lack of awareness and technical knowledge

Smallholder farmers struggle with both inadequate awareness of agroforestry systems as well as a lack of required technical understanding, needed for their implementation and management.

Financial constraints

Physical money problems that involve initial tree plantation costs along with maintenance and long gestation periods discourage farmers from adopting agroforestry. A lack of credit availability alongside insufficient financial supports exacerbates this issue.

Land tenure and policy gaps



Tree integration within farming systems becomes less attractive for farmers because of complex regulations pertaining to tree planting and insecure land ownership. Although policies like the National Agroforestry Policy (2014) aim to address these issues, implementation remains inconsistent.

Market limitations

The absence of market development for agroforestry products like timber, fruits, and medicinal plants reduces the economic motivation for farmers to engage in agroforestry practices.

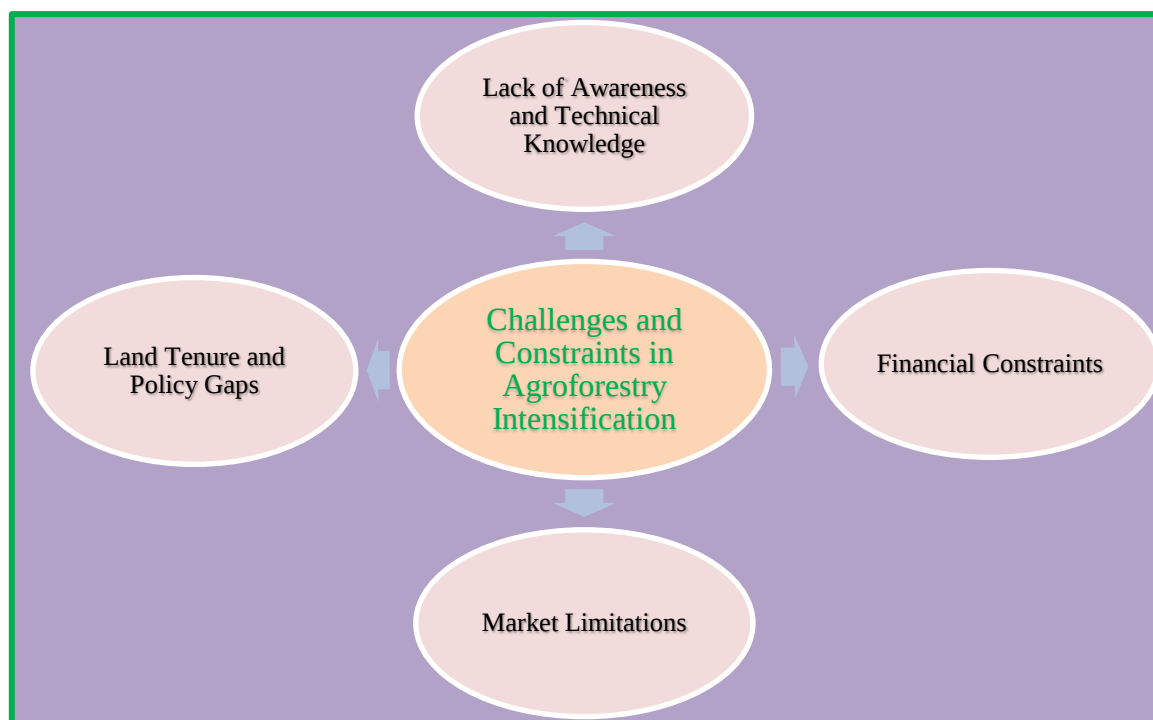


Fig. 1: Challenges and Constraints in Agroforestry Intensification

Future perspectives and recommendations

To enhance the adoption of agroforestry intensification, the following strategies should be considered:

Policy Strengthening and Implementation

Effective implementation of agroforestry policies will be achieved by simplifying regulations for tree harvesting and by promoting land tenure security.

Financial Support and Incentives

By encouraging smallholder farmers to adopt agroforestry practices, financial

assistance can be provided through subsidy programs and low-cost lending options as well as economic motivators.

Market Development

Establishing organized markets and developing improved value chains for agroforestry products to improve economic returns.

Capacity Building and Extension Services

Conducting farmer training programs, and developing knowledge-sharing platforms together with collaborative research to



enhance both awareness and skill development.

Conclusion

Agroforestry intensification offers a powerful pathway for improving smallholder livelihoods, enhancing farm productivity, and strengthening climate resilience in India. Its capacity to sequester carbon, conserve biodiversity, and support sustainable water use underscores its importance in resilient agricultural landscapes. However, widespread adoption requires stronger policy support, improved financial incentives, and accessible technological innovations. Advancing agroforestry demands coordinated efforts among policymakers, researchers, and farmers to ensure systems that are economically viable, socially inclusive, and environmentally sustainable. The long-term success of agroforestry ultimately depends on collaborative actions that promote innovation, address constraints, and build resilient livelihood opportunities for smallholder farming communities in India.

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Mycosilviculture - An emerging tool in forest management

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Forests beyond timber: the rise of Mycosilviculture

For centuries, forest management was dominated by timber production, with wood valued as the primary output for construction, fuel, and industry. While this focus contributed to economic development, it often overlooked the wealth of non-timber forest products (NTFPs)—mushrooms, resins, fruits, and medicinal plants—that have long supported local livelihoods and cultural traditions (Amusa et al., 2024). In recent years, a paradigm shift towards multifunctional forest management has emerged, emphasizing forests as providers of diverse ecological, economic, and social benefits. Mushrooms stand out among NTFPs for their nutritional, medicinal, and economic value, as well as for the critical ecological roles played by the fungi that produce them (Bastos et al., 2023). This has given rise to the concept of **mycosilviculture**—the integration of fungal resources into silvicultural practices. Rather than managing forests solely for trees, mycosilviculture recognizes the symbiotic partnerships between fungi and their hosts (Tomao et al., 2017). Ectomycorrhizal fungi form associations with tree roots, enhancing nutrient cycling, carbon sequestration and forest resilience while also producing edible mushrooms of high cultural and economic importance, such as truffles,

porcini, chanterelles and matsutake (Savoie&Largeteau, 2011). Although the term is relatively new, the practice has deep roots. Rural and indigenous communities worldwide have harvested wild fungi for centuries, not only as food but also as medicine and in rituals. Today, scientific understanding of fungal ecology provides the tools to deliberately enhance their productivity within managed forests. By bridging conservation and production, mycosilviculture represents a forward-looking model of forest management. It addresses global challenges such as food security, biodiversity loss and climate change, while diversifying economic opportunities for forest-dependent communities. In this vision, forests are no longer valued only for timber but as living systems that sustains both people and ecosystems through the integration of fungi.

What is Mycosilviculture?

Mycosilviculture can be broadly defined as the silvicultural management of forest stands to enhance fungal productivity, especially mushrooms of economic, ecological or cultural significance (Tomao et al., 2017). Unlike conventional mushroom cultivation, which is usually based on saprotrophic fungi grown on substrates like straw or logs, mycosilviculture primarily focuses on ectomycorrhizal fungi (ECM)—the mutualistic partners of forest trees. These



fungi form symbiotic associations with host roots through specialized structures such as the Hartig net, where tree-derived carbon is exchanged for soil-derived nutrients such as nitrogen, phosphorus, and micronutrients. This hidden underground partnership strengthens tree health, enhances resilience against drought or pathogens and simultaneously produces highly prized mushrooms like truffles, porcini, chanterelles, and matsutake (Hawkinson et al., 2015). Yet mycosilviculture extends beyond mushroom harvesting. It is increasingly recognized as an ecological forest management technique that embraces both ectomycorrhizal and saprotrophic fungi to enrich ecosystems. Forest fungi play irreplaceable roles in regulating carbon dynamics, nutrient cycling, decomposition processes, and stand resilience. They act as critical drivers of forest stability, influencing everything from soil fertility to plant community composition. Indeed, it is often said that “there are no forests without fungi,” underscoring their centrality in ecosystem functioning (Dominguez-Nunez et al., 2022).

Environmental and anthropogenic factors strongly shape fungal diversity. While

weather patterns, soil conditions, and site-specific features may lie beyond human control, silvicultural practices directly affect fungal communities and their associated ecosystem services. By manipulating stand structure, dynamics, and disturbance regimes, forest managers can influence carbohydrate allocation from trees to fungi, soil water retention and microclimatic conditions. Thinning, controlled disturbance and deliberate inoculation of tree seedlings with selected fungi are all tools within the mycosilvicultural framework. In this sense, mycosilviculture is both an art and a science—the art of balancing ecological processes with human needs, and the science of managing the establishment, development and quality of forest plants in ways that enhance fungal productivity. Its aim is to harness the entire spectrum of ecosystem services provided by forest fungi, from biodiversity conservation and carbon sequestration to food, medicine, and cultural values. As a novel silvicultural concept, mycosilviculture signals a move towards forests managed not only for timber but as living, dynamic systems where fungi are central actors in sustaining ecological stability and human well-being.

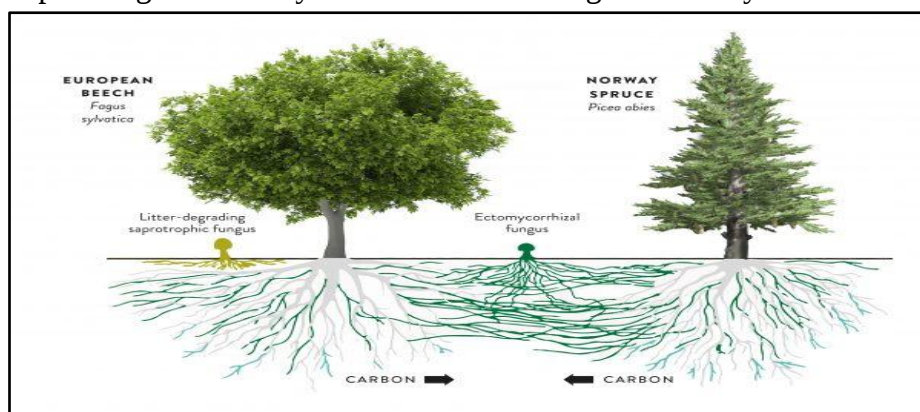


Figure 1: Wood Wide Web: How trees share resources



Figure 1 demonstrates the Wood Wide Web, the underground fungal network that interconnects trees across species (<https://www.civildaily.com/news/what-is-wood-wide-web/>). On the left, a European beech is shown with litter-degrading saprotrophic fungi that recycle organic debris. In contrast, ectomycorrhizal fungi form symbiotic relationships with both beech and Norway spruce roots, creating an extensive shared network. Through this mycelial bridge, carbon flows bidirectionally between the two trees, enabling resource sharing and buffering against stress. Such exchanges highlight that forests function not as isolated individuals but as cooperative communities, where fungi mediate energy transfer, nutrient cycling, and resilience. This invisible infrastructure is central to mycosilviculture, which seeks to harness these natural processes to sustain biodiversity and forest productivity.

Mechanisms: How fungi drive forest ecosystems?

The success of mycosilviculture is rooted in the ecological mechanisms by which fungi, particularly mushrooms and their mycelial networks, sustain forest ecosystems. Far from being passive organisms, mushrooms are active agents of nutrient cycling, soil fertility, and community regulation in both riparian and woodland environments. One of their most significant contributions is the mobilization and recycling of phosphorus. Mycelium—the vast underground network of fungal filaments—extracts phosphorus and other mineral salts from soil particles and transports them across long distances, effectively extending the root system of trees. When mushrooms decay or the

mycelium dies, these stored nutrients are released back into the soil. Decomposer bacteria then rapidly absorb the phosphorus and reintroduce it into the nutritional bank of the ecosystem, where it becomes available to plants and other organisms. This continuous cycle ensures that critical minerals such as phosphorus, potassium, and zinc are not lost but instead redeposited, maintaining soil fertility and promoting plant health.

Mushrooms also act as catalysts for microbial communities. Their presence stimulates the proliferation of bacterial populations, many of which are vital for plant growth. By exerting selective pressure, fungi help shape microbial assemblages that regulate nitrogen uptake and retention, balance soil chemistry, and protect plants against pathogens. In this way, fungi indirectly improve plant productivity and resilience while stabilizing ecosystem processes. Decomposition further reinforces this role. Dead and decaying mushrooms are consumed by a wide range of organisms, from invertebrates to microbes, creating a fast nutrient turnover system. As plants shed leaves, flowers, and branches, fungi continue the breakdown process, ensuring that organic matter is rapidly converted into bioavailable nutrients. This feedback loop supports not just individual trees but the regeneration of the entire habitat. Through these mechanisms, fungi act as nature's insurance policy for resilience. They enable forests to recover quickly from disturbances by accelerating nutrient cycling and fostering conditions for regrowth. In essence, mycosilviculture harnesses these natural processes—using



fungi as ecological engineers—to enhance forest stability, productivity, and adaptability in the face of environmental change.

The illustration below highlights the complex web of interactions in forest soils, where fungi serve as mediators between plants, microbes, and nutrients. Symbiotic mycorrhizal fungi connect tree roots with surrounding plants, channeling minerals, water, and even chemical signals through the “Wood Wide Web.” Saprotrophic

fungi decompose organic debris, while bacteria in the soil further recycle released compounds, ensuring continuous nutrient turnover. The exchange of carbohydrates from plants and minerals from fungi illustrates a balanced partnership that sustains productivity. Beyond nutrient transfer, these underground connections also enable interspecific communication, enhancing cooperation and resilience across the entire forest ecosystem (Lim & Shu, 2022).

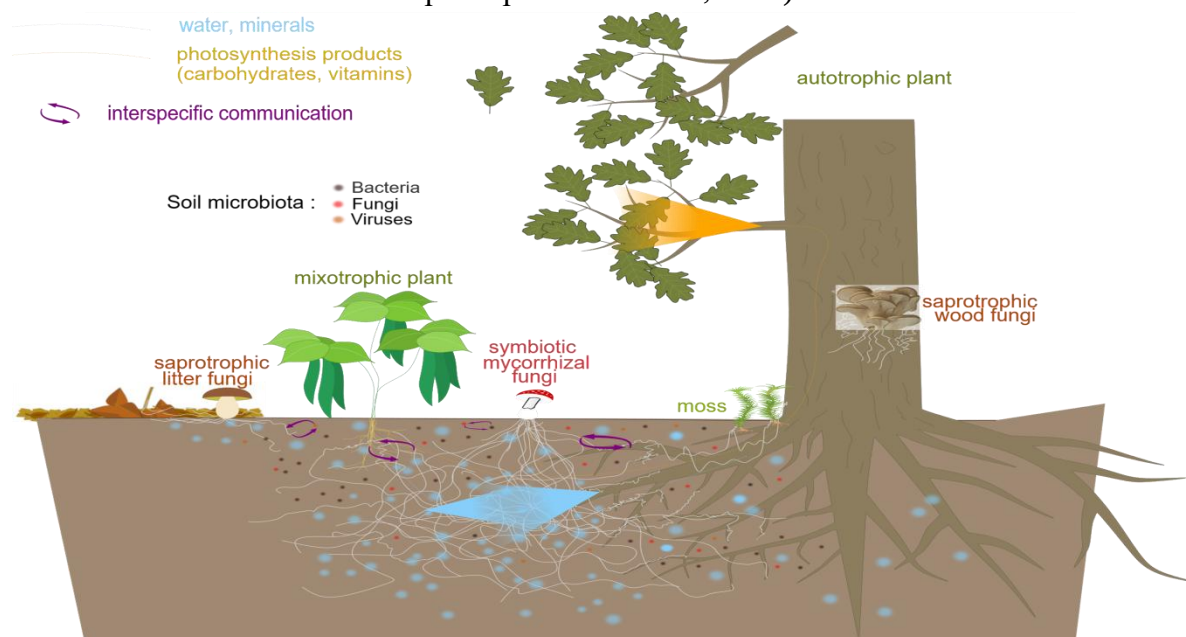


Figure 2: Hidden mechanisms: Fungi as engineers of forest ecosystems

Edible mycorrhizal fungi: A hidden treasure

Hidden beneath forest floors lays a treasure trove that is only occasionally revealed when mushrooms push through the soil surface. These are the fruiting bodies of ECM, organisms that not only sustain trees through nutrient exchange but also provide humanity with some of the most cherished foods in the world. Globally, more than 970 species of edible ectomycorrhizal fungi have been recorded, ranging from gourmet delicacies

to staples of local diets. Among the most famous are truffles in Europe, matsutake in Japan, porcini (*Boletus edulis*) in Mediterranean countries, and chanterelles across temperate forests. These mushrooms are highly prized not just for their unique flavors and aromas but also for their nutritional and medicinal value. They are rich in proteins, vitamins, essential amino acids, and bioactive compounds with antioxidant, antimicrobial, and immune-boosting properties. Beyond their role in fine



cuisine, these fungi hold deep cultural significance. In many rural and indigenous communities, mushroom harvesting is a seasonal ritual tied to traditional knowledge and local identity. In Spain and Italy, mushroom foraging is a cherished autumn activity; in Mexico, wild edible fungi are sold in bustling markets; in Asia, matsutake mushrooms are celebrated in festivals and fetch premium prices as symbols of prosperity (Perez-Moreno et al., 2021).

Economically, edible mycorrhizal fungi can rival or even surpass timber in value. In some Spanish forests, for example, annual mushroom harvests bring more revenue than wood sales. Truffles, one of the most luxurious forest products, can sell for thousands of dollars per kilogram, supporting specialized industries and local economies. This dual value—ecological and economic—makes ECM fungi powerful allies in promoting multifunctional forestry. Yet their importance extends further: they contribute to food security and rural livelihoods, particularly in regions where alternative income sources are scarce. Unlike intensive mushroom farming of saprotrophic species such as oyster or button mushrooms, ECM fungi are intimately tied to forest health. Their productivity depends on ecological balance, meaning that their conservation aligns naturally with sustainable forest management.

Mycosilviculture in practice: Global experiences

While the concept of mycosilviculture is still emerging in formal forestry, examples from around the world demonstrate its practical potential. These experiences

highlight how integrating fungal productivity into forest management can benefit both ecosystems and people. One of the best-known cases comes from Spain, where edible mushroom harvesting is a major part of rural economies. In regions such as Catalonia and Castilla y León, the collection of species like *Boletus edulis* (porcini) and *Lactarius deliciosus* (saffron milk cap) generates more revenue in some years than timber sales (Dominguez-Nunez & Oliet, 2023). To manage this resource sustainably, Spain has pioneered systems of regulated harvesting, permits, and community-based management. These approaches ensure that fungal populations are conserved while supporting local livelihoods. In France and Italy, truffle cultivation provides another striking example. Truffles, the fruiting bodies of ectomycorrhizal fungi, have been deliberately integrated into managed forests and plantations for centuries. By inoculating oak or hazelnut seedlings with truffle spores, foresters have created “truffle orchards” that yield one of the world’s most valuable culinary products. This practice not only supports rural economies but also maintains traditional landscapes (Savoie & Largeteau, 2011).

Moving eastward, Japan and China provide the iconic example of matsutake mushrooms (*Tricholoma matsutake*), which grow in association with pine forests. These mushrooms are culturally revered, symbolizing prosperity and longevity and fetch high market prices. However, matsutake yields have declined due to habitat loss and forest degradation. As a result, forest managers are experimenting with selective thinning, controlled burning, and planting to restore



the pine–matsutake ecosystem—a form of applied mycosilviculture (Kues & Liu, 2000). In Mexico, indigenous communities have long relied on wild edible mushrooms as part of their diet and local markets. Species such as chanterelles, russulas and boletes are sold fresh or dried, representing an important source of seasonal income. Here, traditional knowledge of fungal ecology guides sustainable harvest practices, demonstrating how cultural heritage and ecological understanding can inform modern forestry (Perez-Moreno et al., 2021). Across these regions, the common thread is clear: mycosilviculture diversifies forest outputs. Whether through truffle orchards in Europe, mushroom-rich pine forests in Asia or community harvests in Latin America, these practices showcase the potential of fungi to complement timber, strengthen rural economies and reinforce biodiversity. At the same time, they highlight challenges—climate change, overharvesting and inconsistent policies—that must be addressed for mycosilviculture to thrive globally.

Opportunities and challenges ahead

Mycosilviculture represents an innovative step in rethinking how we manage forests, blending ecological knowledge with human needs. As the practice develops, it offers several opportunities that align with global sustainability goals, while also presenting significant challenges that must be addressed. One of the greatest opportunities lies in biodiversity conservation. By managing forests not only for trees but also for fungi, mycosilviculture encourages the protection of entire ecosystems. Ectomycorrhizal fungi are keystone organisms, and

enhancing their presence supports a wide web of ecological processes—from nutrient cycling to soil formation. At a time when biodiversity is under unprecedented threat, integrating fungi into management ensures that conservation is practical and productive. A second opportunity is in climate change mitigation. Mycorrhizal fungi contribute significantly to carbon sequestration by transferring carbon from trees into stable soil pools. At the same time, fungal-driven nutrient cycling improves tree growth and resilience under stress conditions such as drought. Forests managed with fungi in mind can therefore act as more robust carbon sinks, contributing to climate action strategies. Economically, mycosilviculture holds promise for food security and rural development. Edible fungi provide high-quality protein, essential nutrients and valuable income. They can reduce dependence on timber revenues and diversify livelihoods, especially in forest-dependent communities. This multifunctional approach fits well with international calls for nature-based solutions to economic and ecological challenges.

However, several challenges remain. The productivity of edible mycorrhizal fungi is highly variable, influenced by weather patterns, soil conditions and forest management history. Unlike saprotrophic mushrooms that can be cultivated in controlled conditions, ECM fungi are tied to complex ecological networks, making their yields difficult to predict or standardize. There are also management and policy challenges. Overharvesting, lack of regulations and inadequate monitoring threaten fungal populations in



many regions. At the same time, commercialization risks excluding local communities who have traditionally relied on mushrooms for subsistence. Ensuring equitable benefit-sharing is essential if mycosilviculture is to support both conservation and livelihoods. Finally, research gaps remain. Despite growing interest, much is still unknown about the long-term effects of silvicultural interventions on fungal diversity, productivity, and ecosystem services. Expanding scientific research and incorporating traditional knowledge will be a key to unlocking the full potential of this field.

Conclusion

Forests are no longer seen merely as sources of timber, but as living systems that provide food, medicine, cultural values, and climate resilience. Within this broader vision, mycosilviculture emerges as a powerful tool that unites ecological understanding with human needs. By integrating fungi into forest management, we recognize their roles as nutrient recyclers, ecosystem engineers, and providers of highly valued edible products. Experiences from Europe, Asia, and Latin America show that fungi can rival timber in economic importance while supporting biodiversity and cultural traditions. From truffle orchards in France to matsutake pine forests in Japan and community mushroom harvests in Mexico, these examples highlight the global relevance of managing forests for both trees and fungi. At the same time, challenges remain: unpredictable yields, climate pressures, and the risk of inequitable commercialization. Meeting these challenges will require scientific

research, policy innovation, and respect for traditional knowledge. Ultimately, mycosilviculture offers a vision of forests where production and conservation coexist—where fungi sustain trees, trees sustain people, and people sustain forests. As pressures on ecosystems intensify, embracing this approach could shape resilient, multifunctional landscapes that nourish both biodiversity and humanity. The forests of the future will thrive not through timber alone, but through the hidden partnerships of fungi beneath our feet.

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Pongamia pinnata (L.) Pierre (पोंगामिया पिन्नाटा) के पत्तों पर गॉल माइट (*Aceria pongamiae*) का प्रकोप

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पौधे का परिचय

पोंगामिया पिन्नाटा (*Pongamia pinnata*), जिसे सामान्यतः करंज के नाम से जाना जाता है, एक मध्यम आकार का पर्णपाती वृक्ष है, जो Fabaceae (Leguminosae) कुल का सदस्य है। करंज एक बहु उपयोगी वृक्ष प्रजाति है, जिसका प्रयोग चारा, औषधि तथा जैव-ईंधन उत्पादन में किया जाता है। यह मध्यम आकार का, तेजी से बढ़ने वाला, सदाबहार वृक्ष है जो सामान्यतः 15–20 मीटर ऊँचाई तक पाया जाता है। इसका छत्र (canopy) घना और चौड़ा होता है।

1. पत्तियाँ (Leaves): संयुक्त (compound), परस्पर विन्यस्त, 5–7 पत्रक वाली, अंडाकार (ovate) आकारकी।
2. फूल (Flowers): छोटे, सफेद से गुलाबी-बैंगनी रंग के, गुच्छों (racemes) में लगते हैं।
3. फल (Pods): सपाट, कठोर, बीजयुक्त। प्रत्येक फल में प्रायः 1–2 बीज पाए जाते हैं।
4. बीज (Seeds): कठोर, भूरे, तैलीय। बीजों में 30–40% तक तेल पाया जाता है।

करंज का आर्थिक एवं पारिस्थितिक महत्व अत्यधिक है। इसके बीजों से प्राप्त तेल का उपयोग बायो डीज़ल निर्माण, साबुन, मोमबत्ती और औषधियों में किया जाता है। वृक्ष की पत्तियाँ,

छाल एवं बीज में औषधीय गुण पाए जाते हैं। यह वृक्ष नाइट्रोजन स्थिरीकरण (Nitrogen fixation) में सक्षम है, जिससे यह मृदा उर्वरता में सुधार करता है। यह भारतीय परंपरा में औषधीय वृक्षों की श्रेणी में एक विशिष्ट स्थान रखता है। इसका उपयोग श्वसन तंत्र से जुड़ी बीमारियों जैसे *श्वासनली शोथ (ब्रोंकाइटिस)*, *काली खाँसी*, *गठिया* के अतिरिक्त *अतिसार (दस्त)*, *अजीर्ण*, *अधिक वायु विकार (गैस)*, *सूजाक (गोनोरिया)*, *कुष्ठरोग* तथा *अर्बुद (ट्यूमर)* तक के उपचार में होता आया है। यह यह मृदा अपरदन नियंत्रण, कार्बन अवशोषण तथा हरित क्षेत्र संवर्धन में महत्वपूर्ण भूमिका निभाता है। इसीलिए इसे नर्सरी एवं वनीकरण कार्यक्रमों में व्यापक रूप से प्रयोग किया जाता है।

प्राकृतिक वितरण

पोंगामिया पिन्नाटा मूलतः दक्षिण-एशिया का वृक्ष है। यह भारत, श्रीलंका, म्यांमार, थाईलैंड और इंडोनेशिया में प्राकृतिक रूप से पाया जाता है। भारत में यह समुद्र-तटीय क्षेत्रों से लेकर अर्ध-शुष्क और उपोष्ण कटिबंधीय क्षेत्रों तक देखा जा सकता है।

वैज्ञानिक वर्गीकरण (Taxonomical Classification):

Kingdom (जगत): Plantae

Subkingdom (उपजगत): Tracheobionta
(Vascular plants)



Division (विभाग): Magnoliophyta
(Angiosperms)

Class (वर्ग): Magnoliopsida (Dicotyledons)

Order (गण): Fabales

Family (कुल): Fabaceae (Leguminosae)

Subfamily (उपकुल): Papilionoideae

Genus (वंश): Pongamia

Species (प्रजाति): *Pongamiapinnata* (L.)
Pierre

Synonyms (पर्याय): *Derris indica*, *Millettia pinnata*

सामान्यनाम (Common Names):

हिंदी: करंज / पोंगामिया

अंग्रेज़ी: Karanja, Indian Beech, Pongam Oil Tree

संस्कृत: करंज, नक्तमाल

तमिल: புங்கைமரம் (Pungaimaram)

तेलुगु: Kanuga

आर्थिक और पर्यावरणीय महत्व (Economic & Ecological Importance)

ईंधन: बीज से प्राप्त तेल का प्रयोग बायो डीज़ल उत्पादन में।

औषधीय उपयोग: पत्तियों, छाल और बीजों का उपयोग आयुर्वेद में त्वचा रोग, दाद-खाज, घाव भरने, श्वसन रोगों, पाचन संबंधी विकारों और सूजन जैसी समस्याओं के उपचार में किया जाता है।

कीट-नाशक के रूप में उपयोग किया जाता है।

चारा: पत्तियाँ पशुओं के लिए पोषक चारे का स्रोत।

मृदासंरक्षण: नाइट्रोजन स्थिरीकरण (nitrogen fixation) क्षमता के कारण यह मृदा उर्वरता बढ़ाता है।

पर्यावरणीय भूमिका: तटीय क्षेत्रों में कटाव रोकने, छाया देने और प्रदूषण शोषण में सहायक।

पोंगामिया पिन्नाटा के पत्तों पर गॉल का प्रकोप

नर्सरी स्तर पर पत्तियों पर गॉल बनने की समस्या वृक्ष की वृद्धि एवं गुणवत्ता को प्रभावित कर सकती है। इस अध्ययन में करंज पौधों पर गॉल के प्रकोप का आकलन किया गया।

इस वृक्ष पर पाई जानेवाली *एसेरिया पोंगामिए* नामक अति-विशिष्ट एरियोफिडमाइट केवल इसी पौधे की परजीवी है। पोंगामिया पिन्नाटा पर गॉलमाइट (*Aceria pongamiae*) के कारण पत्तियों पर असामान्य अंगुलीनुमा गांठनुमा संरचनाएँ, जिन्हें गॉल्स कहा जाता है, उत्पन्न करती है। एक ही पत्ती पर गॉल्स की संख्या अलग-अलग हो सकती है। और कई बार ये गॉल्स आपस में जुड़कर अनियमित आकार की बड़ी संरचनाएँ बना लेते हैं, जो पूरी पत्ती की सतह, मध्यशिरा, नसों और शिराओं को ढकलेती हैं। यह लक्षण न केवल पत्तियों की सौंदर्यात्मक गुणवत्ता घटाता है, बल्कि प्रकाश संश्लेषण और पौधों की समग्र वृद्धि पर प्रतिकूल प्रभाव डालता है। नर्सरी स्तर पर गॉल का प्रकोप पौधशाला की सफलता दर को सीधे प्रभावित कर सकता है।

वर्ष 2025 के दौरान Jodhpur, Beawar एवं sendra स्थित नर्सरी में सर्वेक्षण किया गया। कुल 100 पौधों का चयन कर पत्तियों की जाँच की गई। प्रत्येक पौधे पर गॉल की उपस्थिति/अनुपस्थिति दर्ज की गई और प्रकोप प्रतिशत की गणना की गई।





Aceria pongamiae द्वारा कोमल पत्तियों पर गॉल्स का निर्माण एवं विकास



पोंगामिया कि पत्तियों पर गॉल्स का गंभीर प्रकोप

सर्वेक्षण के दौरान यह पाया गया कि पोंगामिया पिन्नाटा के पौधों पर गॉल माइट (*Aceria pongamiae*) का गंभीर प्रकोप व्याप्त है। नर्सरी स्तर पर लगभग 58% पौधे गॉल माइट के संक्रमण से प्रभावित पाए गए। संक्रमित पौधों की पत्तियों पर गोलाकार, हरे रंग की गॉल्स विकसित होती देखी गई, जो धीरे-धीरे आकार में बढ़ती गई। इन गॉल्सके कारण पत्तियों का हरित क्षेत्र कम हो गया, जिससे प्रकाश संश्लेषण प्रभावित हुआ और पौधों की वृद्धि पर नकारात्मक प्रभाव पड़ा।

संक्रमण की उन्नत अवस्था में पत्तियाँ पीली पड़कर मुरझाने तथा समय से पूर्व झड़ने लगती हैं, जिससे पौधों की समग्र गुणवत्ता और जीवन शक्ति में कमी आती है। नर्सरी स्तर पर गॉल का इतना अधिक प्रकोप इस बात का संकेत है कि गॉलमाइट का प्रबंधन समय रहते न किया जाए तो पौधों की वृद्धि तथा रोपण योग्य पौध सामग्री की उपलब्धता गंभीर रूप से प्रभावित हो सकती है। गॉल बनने से प्रकाश संश्लेषण क्षेत्र में कमी आती है, जिससे पौधे की जड़ों और तनों की वृद्धि भी अवरुद्ध होती है।



निष्कर्ष

यह अध्ययन दर्शाता है कि पोंगामिया पिन्नाटा की नर्सरी में गॉल माइट (*Aceria pongamiae*) का संक्रमण व्यापक रूप से पाया गया है। सर्वेक्षण के दौरान लगभग 58% पौधों की पत्तियों पर गॉल्स का गंभीर प्रकोप दर्ज किया गया। यह स्थिति पौधों की वृद्धि एवं गुणवत्ता पर प्रतिकूल प्रभाव डाल सकती है। अतः गॉल माइट के प्रभावी

प्रबंधन हेतु नर्सरी स्तर पर नियमित निगरानी की आवश्यकता है। संक्रमित पत्तियों को शीघ्र हटाकर नष्ट करना, जैव-नियंत्रण उपाय अपनाना तथा आवश्यकता पड़ने पर उपयुक्त माइटिसाइड जैसे फेनाज़ाक्विन (Fenazaquin) या प्रोपार्जिट (Propargite) का नियंत्रित प्रयोग किया जाना चाहिए।



Production, decomposition, and the role of microbes in litter of Eucalyptus and Casuarina plantations in Telangana

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Eucalyptus and Casuarina are two workhorse tree groups for wood and pulp in peninsular India. In Telangana, they're widely planted by the Telangana State Forest Development Corporation (TSFDC) and farmers alike. Their fallen leaves, twigs, and shed bark—together called “litter”—quietly feed soils, recycle nutrients, and store carbon.

What is “litter” and why does it matter?

Tree litter is the carpet of freshly fallen leaves, twigs, and other plant parts on the plantation floor. As this blanket breaks down, nutrients locked in the litter (like nitrogen, phosphorus, and potassium) is released back to the soil. That's good for tree growth, soil health, and long-term carbon storage. In Telangana, TSFDC's working plans note large areas under Eucalyptus and Casuarina, so their litter dynamics matter at landscape scale.

How much litter do these plantations make?

Eucalyptus: Recent plantation studies report ~4–5 tonnes of litter per hectare per year in managed stands—most of it leaves, with the rest small branches and other bits. **Casuarina:** Estimates vary with rainfall, site, and management. A government factsheet from IFGTB's ENVIS centre reports up to ~30 t/ha/yr in dense stands, but more typical literature values cluster lower. A 2025 study places Casuarina litter production around 3.3–11 t/ha/yr.

What controls how fast litter decomposes?

Climate & season

Warm, moist conditions speed decay; hot and dry conditions slow it.

Litter quality

Litter richer in nitrogen and with lower lignin decomposes faster. Eucalypt litter is often waxy and lignin-rich, so it breaks down moderately fast.

Decomposer community

Microbes (bacteria and fungi) do most of the chemical work, helped by tiny fauna (mites, springtails) that shred litter and increase the surface area for microbes.

Decomposition rates

Eucalyptus litter

Leaf litter half-lives around 10–12 months. Fine-wood decomposes more slowly.

Casuarina litter

Thick needle mats decompose slower in dry seasons but accelerate with monsoon rains. Microbes and earthworms together can speed breakdown.

Microbes: the invisible engine

Seasonal microbial shifts

Microbial communities and enzyme activities swing with seasons. Faster decomposition occurs after rains, slower during dry months.

Enzymes matter

Microbes deploy enzymes (cellulases, ligninases) to unlock carbon and nutrients. Better nutrient status stimulates microbial diversity and enzyme activity.



Telangana soils under plantations A 2022 study comparing TSFDC-managed vs. farm-grown Eucalyptus found higher soil organic carbon (0.59–0.88%) and increased N, P, K with stand age, reflecting steady litter inputs and decomposition.

Practical pointers for managers:

Keep the litter layer

Avoid raking or burning. Retaining litter maintains soil moisture and feeds microbes.

Mind seasonality

Plan pruning and soil amendments with the onset of rains for maximum microbial activity.

Diversity

Mixed residues or intercrops improve litter quality and support richer decomposer communities.

Monitor soil

Simple soil tests every few years confirm nutrient cycling and organic carbon status.

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Quercus glauca- an important fodder tree species

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Introduction

Quercus glauca is an important tree species that belongs to family Fagaceae. It is a middle-sized evergreen tree having a dense rounded crown and clean large cylindrical trunk (Singh et al., 2010). It is found in the altitudinal range of 900-1800m (Singh and Singh, 1987). This species prefers moist, cool environments with adequate light conditions for optimal growth (Orwa et al., 2009). It grows in the valleys of outer Himalayas, ascending up to about 1800m elevation and also in Khasi hills. The natural regeneration of this species is sporadic in nature and poor due to anthropogenic disturbance and consumption of its acorns by herbivores (Himalayan langur, *Presbytis entellus*) (Upreti et al., 1985). *Q. glauca* is found in restricted areas usually in moist and shady areas of river basins and deep valleys (Ito et al., 2007).

Q. glauca provides a range of benefits to local communities. The seeds, after leaching out the bitter tannins with running water or streams, can be consumed as food. Its leaves are extensively used as fodder. The tree is lopped for fodder in North-West Himalayas (Gorrie, 1937). Tannin, which can be extracted from stem galls, serves as a dyestuff. The wood of this species is known for its high quality, featuring a fine texture and straight grain. It is both hard and relatively durable, making it suitable for various applications,

including heavy and light construction, railway sleepers, poles, posts, stakes, and furniture. Traditionally, *Q. glauca* has also been utilized in medicine for treating hemorrhoids (Zulfiqar et al., 2015; Singh et al., 2010).

Distribution

Q. glauca is found in secondary evergreen broadleaf forests at elevations ranging from 300 to 3100 meters in the northern subtropical and warmer temperate regions of Asia (Orwa et al., 2009), and at altitudes between 1500 and 2500 meters in India (Singh and Rawat, 2000). This species thrives in light to medium-textured, well-drained soils with an acidic to neutral pH, and can also grow in shallow, nutrient-poor soils. It typically receives annual rainfall between 1000 and 2900 mm and experiences average temperatures ranging from 6 to 19°C. While *Q. glauca* can tolerate significant shading during its early stages, it needs full overhead light as it matures (Orwa et al., 2009) and prefers humid conditions (Gaur, 1999; Wangda and Ohsava, 2006). In Himachal, it has been reported in Chamba, Kangra, Kullu, Mandi and Shimla Districts (Chowdhery and Wadhwa, 1984).

Phenology

Q. glauca is a large evergreen tree characterized by its 4-sided leafy buds, silky new shoots, and sharply serrated upper leaf surfaces (Brandis, 1874; Hooker, 1879). Its green, alternate leaves



are simple, with serrated edges, and have an elliptic to lanceolate shape with pinnate venation. The leaf surfaces are glossy on top and glaucous and pubescent underneath (Gilman and Watson, 1994; Osmoston, 1927).

According to Upadhaya et al. (2018), *Q. glauca* produces yellow flowers from March to May, and brown nuts from September to January. Additionally, new leaves emerge from April to May, leaf damage occurs from January to March, and leaf senescence happens in April-May (Chand et al., 2017). Seed collection is carried out from October to December (Amare and Bhardwaj, 2016).

Silviculture

This oak species is moderately light-demanding but can tolerate substantial shade. It flourishes in moist, fertile soils and does not perform well in dry conditions. It readily coppices (Troup, 1921). Multi-stemming, an important regeneration strategy, is observed in *Q. glauca* (Rao et al., 2020). The population of *Q. glauca* is higher on wetter and more nutrient-rich sites, while it declines with accumulation of available phosphorus, soil pH and solar radiation (Amare and Bhardwaj, 2017).

Natural regeneration

Under natural conditions, germination of *Q. glauca* typically begins early in the rainy season, around July. However, in particularly moist areas, seeds may start germinating as early as May. Research conducted in Dehradun has demonstrated that seeds left exposed to the sun for extended periods tend to crack and lose their viability. For successful germination, it is crucial that seeds are either quickly buried after falling, or placed in very moist

ground or shaded areas. Natural regeneration occurs under moderate shade, but once the young plants are established, they generally benefit from full overhead light. In extremely moist, nearly swampy areas, thickets of naturally regenerated plants are sometimes found (Troup, 1921). Upreti et al., 1985 highlighted the problem of natural regeneration in *Q. glauca*. The natural regeneration of this species is sporadic in nature and poor due to anthropogenic disturbance and consumption of its acorns by herbivores (Himalayan langur, *Presbytis entellus*) (Upreti et al., 1985).

Nursery techniques

Seed collection

Mature seeds are gathered from November to December. Before storage, the seeds should be dried in a shaded area rather than in direct sunlight. They can remain viable for several months; for instance, seeds stored for eight months in Dehradun had a germination rate of 90% (Troup, 1921). Approximately 570 seeds equal one kilogram (Ghosh, 1977). Collection of the seeds should take place from September (Purohit et al., 2009) to November (Khan, 2015).

Seed sowing

The species produce short viable seeds, which lose their viability quickly during the seed storage (Purohit et al., 2009), thus sowing of current year collected seed is preferred over the stored seeds.

Planting out

Planting out seedlings from the nursery can be best carried out in the rainy season, the year after sowing (Troup, 1921). Seedlings are taken from the nursery with their root balls intact. Removing the lower leaves helps minimize transpiration and



improves survival rates. Typically, a spacing of 3m x 3m is used. It is essential to properly fence plantation areas to protect them from livestock (Singh, 1982).

Pre-sowing treatments

Scarification has been found to be more effective than stratification as a pre-sowing treatment (Purohit et al., 2009; Khan, 2015).

Nursery requirements

The species grows well in shaded nursery conditions and higher germination, survival and seedling growth characteristics were reported (Amare and Bhardwaj, 2016). The nursery beds require regular watering frequently to keep the sowing media moist (Singh et al., 2010).

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Harnessing multipurpose tree species for the bio-remediation and restoration of degraded soils

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Abstract

Soil degradation and contamination represent one of the most pressing environmental challenges globally, affecting about 33% of the world's soils and nearly 147 million hectares in India (FAO, 2020; ICAR, 2022). The loss of soil fertility due to erosion, salinization, nutrient depletion, and contamination has severely constrained agricultural productivity and ecosystem sustainability. The integration of Multipurpose Tree Species (MPTS) in agroforestry systems offers an effective, low-cost, and ecologically sustainable approach to restore degraded soils. Species such as *Acacia nilotica*, *Leucaena leucocephala*, *Azadirachta indica*, and *Gliricidia sepium* have shown the potential to increase soil organic carbon (SOC) by 0.3–0.6% annually, enhance soil nitrogen content by 20–35%, and reduce soil erosion by up to 50%. The root systems of MPTS improve soil porosity, infiltration, and aeration, while litter fall enriches soil nutrients and microbial activity. In saline and sodic soils, tree species like *Prosopis juliflora*, *Casuarina equisetifolia*, and *Acacia auriculiformis* have demonstrated significant tolerance and reclamation capacity, improving soil structure and reducing electrical conductivity. Bioremediation approaches, including phytoremediation, bio-venting,

and bio-augmentation, further enhance soil detoxification through microbial and plant-based processes. Agroforestry-based restoration systems not only improve soil health and carbon sequestration but also enhance livelihood security and contribute to Sustainable Development Goals (SDGs 1, 2, 13, and 15) by promoting biodiversity and resilience against climate stress.

Keywords: Multipurpose Tree Species (MPTS); Bioremediation; Soil Restoration; Phytoremediation; Sustainable Land Management; Soil Health.

Introduction

Soil degradation and contamination have emerged as critical global concerns, threatening agricultural sustainability and ecosystem functionality. Approximately 33% of the world's soils are moderately to highly degraded due to erosion, nutrient depletion, salinization, compaction, and chemical contamination (FAO, 2020). In India alone, nearly 147 million hectares of land are affected by various forms of degradation, severely constraining crop productivity and livelihood security (ICAR, 2022). Problematic soils whether nutrient-poor, saline, or contaminated with heavy metals pose major limitations to food production and ecological balance. In this context, multipurpose tree species (MPTS) offer a biologically viable and economically sustainable approach to soil



restoration and environmental rehabilitation.

Multipurpose trees not only serve as sources of timber, fodder, fruits, fuelwood, and non-timber products, but also act as natural agents of soil bio-remediation. Species such as *Acacia nilotica*, *Leucaena leucocephala*, *Azadirachta indica*, and *Gliricidia sepium* have shown remarkable potential in phytoremediation, nitrogen fixation, and organic matter enrichment. The deep root systems of these trees enhance soil porosity and water infiltration, while litter fall contributes significantly to soil organic carbon (SOC) accumulation an essential indicator of soil health (Sarvade et al., 2014b; Sarvade et al., 2017; Sarvade et al., 2019). For instance, studies have reported that the integration of MPTS in degraded farmlands can increase SOC by 0.3-0.6% annually and reduce soil erosion by up to 40-50% (Kumar et al., 2021; Lal, 2022). Such improvements not only restore soil fertility but also contribute to long-term carbon sequestration and ecosystem stability.

Agroforestry, as an integrated land-use system, plays a pivotal role in land restoration, climate change mitigation, and food security enhancement (Sarvade et al., 2014a; Sarvade and Singh 2014). By combining trees, crops, and sometimes livestock on the same land unit, agroforestry systems optimize spatial and temporal resource use, improve soil biological activity, and enhance carbon storage both above and below ground. Globally, agroforestry practices are estimated to sequester 0.7-1.6 Pg of carbon per year, significantly contributing to global climate regulation (Nair et al.,

2020). The presence of trees reduces evapotranspiration and moderates microclimatic extremes, improving overall system resilience under climate stress.

Furthermore, the soil stabilization capacity of tree roots mitigates erosion and enhances water infiltration by 25-30%, while leaf litter decomposition promotes nutrient recycling and microbial diversity. These processes help rehabilitate marginal and degraded lands, turning them into productive agroecosystems. From a socio-economic perspective, agroforestry provides diversified income streams for rural communities through food, fodder, fuelwood, gums, resins, and medicinal products directly supporting SDG 1 (No Poverty) and SDG 2 (Zero Hunger). Simultaneously, its contribution to carbon sequestration (SDG 13: Climate Action) and biodiversity conservation (SDG 15: Life on Land) underscores its importance in achieving the United Nations 2030 Agenda for sustainable development (Sarvade 2025a; Sarvade 2025b).

Multipurpose trees are thus deliberately cultivated and managed for more than one output or ecological function. They may yield food products (fruits, nuts, leaves) while simultaneously providing firewood, nitrogen enrichment, or shade for intercrops. In tropical regions, particularly within smallholder and subsistence farming systems, these trees form the foundation of sustainable agroforestry, ensuring both ecological balance and livelihood security. The deliberate integration of MPTS in agroforestry landscapes therefore represents a nature-based solution to contemporary challenges of soil degradation, food insecurity, and climate change bridging the gap between



ecosystem restoration and rural development.

Multipurpose agroforestry trees

Multipurpose tree species are invaluable assets in tropical farming systems, as they provide a variety of products and ecological services from a single planting. A single tree can yield multiple outputs, offering food, fuel, fodder, and soil fertility enhancement simultaneously. For example, *Gliricidia sepium*, widely grown as a live fence in South India, is an outstanding example of a multifunctional species. It provides fuelwood, nutrient-rich fodder, and green manure for agricultural crops all at once (Rao et al., 2020). Similarly, *Leucaena leucocephala*, a fast-growing leguminous species, demonstrates how management practices can determine output type; certain trees are pruned primarily for wood production, while others are managed for leaf meal, enhancing flexibility in farm resource use and productivity (Pandey et al., 2019).

While most trees serve general ecological functions such as providing habitat, shade, and soil improvement, truly multipurpose trees contribute more directly to human well-being by fulfilling multiple subsistence and economic needs. Typically, each species assumes a primary role as a windbreak, living fence, or alley-crop component while also performing one or more secondary roles, such as providing food, fuel, fodder, or green biomass. This multifunctionality allows farmers to meet several essential requirements from the same land area, increasing sustainability and reducing dependency on external inputs. For instance, a multipurpose tree can serve as a windbreak, reducing crop damage from strong winds, while

simultaneously producing edible fruits or pods. In another case, the same tree might be part of a living fence, providing both structural support and firewood for household needs (Nair, 2020).

When integrated into agricultural landscapes, multipurpose trees perform a suite of ecological functions that improve system resilience. They enhance nitrogen availability through biological fixation, contribute to organic matter build-up, and support microbial activity, all of which enrich the soil and promote healthy crop growth. By serving as both productive and protective components, these trees strengthen farming system sustainability and food security, especially in tropical regions where land and resources are often limited. Studies have demonstrated that integrating nitrogen-fixing species such as *Gliricidia sepium* and *Leucaena leucocephala* can increase soil nitrogen content by 20-35% and organic carbon by 0.3-0.6% annually, contributing to long-term fertility and climate resilience (Kumar et al., 2021; Lal, 2022).

Several tree species have become emblematic examples of multipurpose use across the tropics. *Gliricidia sepium* is one of the most widely used species for living fences, fuelwood, fodder, and nitrogen fixation. *Moringa oleifera*, often called the “miracle tree,” provides edible leaves, pods, and seeds, serves as livestock forage, and offers valuable shade to companion crops, though it is not a nitrogen fixer as commonly assumed (Palada and Chang, 2019). The coconut palm (*Cocos nucifera*) exemplifies an all-round resource tree its fruit supplies food and water, while the leaves and husks



are used for roof thatching, shade, and firewood. Likewise, the neem tree (*Azadirachta indica*) is valued for its insecticidal, medicinal, and soil-enriching properties, while also functioning as a windbreak and a source of biomass mulch (Tewari, 2021).

Ideally, most trees integrated into tropical farms should be multipurpose in nature, contributing far more than shade or fuelwood alone. Preference should be given to nitrogen-fixing legumes or species capable of enhancing food and livelihood security (Sarvade et al., 2014a). By cultivating such trees, farmers not only increase their land's productivity but also fortify their systems against climatic and economic uncertainties. The incorporation of multipurpose trees thus represents a cornerstone of sustainable agroforestry, harmonizing ecological restoration with social and economic development.

Features of Good Multipurpose Tree Species (MPTS)

High Organic and Nutrient Content in Foliage

- Leaves rich in nitrogen, phosphorus, and potassium improve soil fertility through litter decomposition.
- Species such as *Leucaena leucocephala*, *Gliricidia sepium*, and *Sesbania grandiflora* contribute 2.5-3.5% nitrogen to the soil.
- These species enhance soil organic carbon and microbial activity. (Kumar et al., 2021; Rao et al., 2020)

Deep Root System with Strong Soil Binding Capacity

- Deep roots anchor soil, reduce erosion, and improve infiltration.
- Species like *Acacia nilotica* and *Prosopis juliflora* help stabilize sloping and degraded lands.
- Roots enhance aeration and water-holding capacity of soil.

(Singh et al., 2022)

Tolerance to Problem Soils

- MPTS can grow in saline, alkaline, or degraded soils where other crops fail.
- Examples include *Casuarina equisetifolia*, *Acacia auriculiformis*, and *Azadirachta indica*.
- Such trees help reclaim wastelands and mined areas by improving soil properties.

(Chaturvedi and Panwar, 2020)

Nitrogen-Fixing and Stabilizing Ability

- Leguminous MPTS form symbiosis with *Rhizobium* or *Frankia* to fix atmospheric nitrogen.
- *Leucaena leucocephala*, *Albizia lebbek*, and *Sesbania sesban* fix 50-500 kg N ha⁻¹ yr⁻¹.
- Reduces dependency on chemical fertilizers and enhances crop productivity.

(Lal, 2022; Nair, 2020)

Trees play a crucial role in maintaining and enhancing soil fertility, a function clearly demonstrated by the high nutrient status and efficient nutrient cycling observed in natural forests, as well as through the restoration of fertility under forest fallows in shifting cultivation and in reclamation forestry and agroforestry practices. They improve soil fertility primarily by increasing nutrient additions,



reducing nutrient losses, and enhancing soil physical, chemical, and biological conditions. Trees contribute organic matter to the soil through leaf litter, twigs, root biomass, and exudates, which enrich soil organic carbon, promote nutrient mineralization, and stimulate microbial activity (Kumar et al., 2021; Nair, 2020). By stabilizing the soil with their extensive root systems, trees reduce runoff and erosion, helping to conserve essential nutrients and retain soil moisture (Chaturvedi & Panwar, 2020). Their litter and root decomposition further improve soil structure, porosity, and cation exchange capacity, while fostering diverse microbial communities that enhance nutrient cycling and overall soil health (Lal, 2022; Nair, 2020).

Among the most important processes by which trees enhance soil fertility are their ability to check runoff and erosion, increase nutrient inputs through nitrogen fixation and nutrient uptake from deep soil horizons, and promote more closed nutrient cycling. Deep-rooted species mobilize nutrients from lower soil layers, making them available to surface crops, while nitrogen-fixing trees enrich the soil naturally without requiring chemical fertilizers. Collectively, these processes demonstrate that integrating trees into farming and land restoration systems is a highly effective strategy for improving soil fertility, sustaining productivity, and supporting long-term ecosystem resilience.

Some MPTs adopted by farmers

Arid Zone

Prosopis cineraria (Khejri), *P. juliflora* (Mesquite tree), *Tecomella indulala* (Rohida), *Zizyphus* spp. (Ber), *Azadirachta indica* (Neem), *Eucalyptus camaeldulensis*

(River red gum), *Acacia tortilis* (Israeli babul).

Semi-arid Zone

Acacia nilotica (Gum Arabic tree / Babul), *Acacia tortilis* (Israeli babul), *Albizia lebbek* (Sirish / Women's tongue), *Albizia amara* (Krishna Siris), *Prosopis juliflora* (Mesquite tree), *Azadirachta indica* (Neem), *Eucalyptus hybrids* (Hybrid Eucalyptus), *Leucaena leucocephala* (Subabul).

Humid Zone

Albizia lebbek (Sirish/ Women's tongue), *Albizia procera* (Safed Sirish), *Paraserianthes falcataria* (Moluccan albizia), *Leucaena leucocephala* (Subabul), *Acacia mangium* (Australian Sag).

Central Indian Plateau

Albizia amara, *Albizia lebbek*, *Acacia nilotica*, *Butea monosperma* (Palash), *Prosopis juliflora*.

Eastern and Western Coastal Region

Casuarina equisetifolia (Saru), *Leucaena leucocephala*, *Prosopis juliflora*.

Temperate Himalayan Region *Ficus* spp., *Alnus* spp., *Salix* spp.

Sub-temperate Lower Hills and Gangetic Plain

Acacia nilotica, *Albizia lebbek*, *Azadirachta indica*, *Melia azedarach* (Pride of India), *Leucaena leucocephala*.

Eastern Himalayan Zone

Acacia mangium, *Acacia auriculiformis* (Akashmani), *Paraserianthes falcataria*, *Albizia lebbek*, *Albizia procera*.

Bio-remediation of problem soils

Remediate means to solve a problem and bio-remediation means to use biological organisms/ agent to solve an environmental problem such as contaminated / problem soils or



contaminated ground water. Bioremediation is the use of microbes to clean up contaminated soil and groundwater. Microbes are very small organisms, such as bacteria, that live naturally in the environment. Bioremediation stimulates the growth of certain microbes that use contaminants as a source of food and energy. Contaminants treated using bioremediation include oil and other petroleum products, solvents, and pesticides.

Problematic soils are these soils which are not suitable for arable farming because of specific limitations. In general, problem soils are two types i.e. physical problem and chemical problems. Agro-forestry systems have the potential tool to make use of marginal and degraded lands through the soil improving effect of trees. It proves to be one of the cheapest and best modes for the reclamation of all problematic soils. Agro-forestry systems like silviculture, silvi-pasture etc. can improve the physical and chemical properties of the soil along with additional return on long-term basis.

1. Bioremediation of physical problems of soils: For the bioremediation of physical problems of soil like sandy soils, subsoil hardening or hardpan, surface crusting, water logged soils, peat and marshy soils etc. Tree species i.e. *Eucalyptus robusta* (Swamp mahogany), *Syzygium cumunii* (Jamun), *Terminalia arjuna* (arjuna), *Salix tetrasperma* (Indian willow), *Dalbergia latifolia* (Shisham), *Eucalyptus camaeldulensis* (River red gum), *Eucalyptus grandis* (Rose gum) and some grasses like *Brachiaria mutica* (Para grass) and *Cynodon dactylon* (Bermuda grass), *Dichanthium caricosum*,

Brachiaria decumbens etc. are commonly used.

Bioremediation of chemical problems of soils

The different chemical problems of soils i.e. salt affected soils (saline, sodic and saline – sodic) etc also reclaimed or managed by the following tree and grass species.

Saline Soils: Promising woody species -

- *Salvadora persica* (mustard tree)
- *Prosopis juliflora* (mesquite tree)
- *Acacia nilotica* (Babul)
- *Butea monosperma* (Palash)
- *Terminalia arjuna* (Arjuna)
- *Dalbergia sissoo* (Sissoo)
- *Casuarina equisetifolia* (Saru)

Highly salt tolerant and high biomass producing grasses species include

- *Aeluropus lagopoides* (mangrove grass or rabbit-foot aeluropus)
- *Suaeda fruticosa* (shrubby seablight)
- *Cynodon dactylon* (Bermuda grass, Dhoob grass)
- *Brachiaria ramosa* (Browntop Millet)
- **Sodic Soils:**
- *Prosopis juliflora* (mesquite tree) and *Dichanthium annulatum* (Karnal grass) improves the soil conditions to such an extent that after some time or year.
- Some fodder species can be grown under trees such as - Berseem (*Trifolium alexandrinum*), Senji (*Melilotus parviflora*) and Shaftal (*Trifolium resupinatum*)

Relative tolerance of fruit trees to sodicity

Exchangeable Sodium	Trees



Percentage (ESP) for Sodicty tolerance	
Sensitive : < 20	<i>Mangifera indica</i> (Mango) <i>Artocarpus heterophyllus</i> (Jack fruit) <i>Musa paradisiaca</i> (Banana)
Low : 20 – 30	<i>Psidium guajava</i> (Guava) <i>Citrus limon</i> (Lemon) <i>Vitis vinifera</i> (Grape)
Medium : 30 – 40	<i>Punica granatum</i> (Pomegranate)
High : 40 – 50	<i>Ziziphus jujube</i> (Ber) <i>Tamarindus indica</i> (Tamarind) <i>Manilkara zapota</i> (Sapota) <i>Phoenix dactylifera</i> (Date palm)

Saline-Sodic Soils

- *Acacia auriculiformis*(Akashmoni)
- *Azadirachta indica*(Neem)
- *Casuarina equisetifolia*(Saru)
- *Dalbergia sissoo*(Sissoo)
- *Ailanthus excels* (tree of heaven)
- *Prosopis cineraria* (Khejri)
- *Acacia tortilis* (Israeli babul)
- *Acacia nilotica*(Babul)

Types of Bioremediation

Based on place where wastes are removed, there are principally two ways of bioremediation:

In-Situ Bioremediation

Most often, in situ bioremediation is applied to eliminate the pollutants in contaminated soils and groundwater. It is a superior method for the cleaning of contaminated environments because it saves transportation costs and uses harmless microorganisms to eliminate the chemical contaminations. Two types of in situ bioremediation are distinguished

based on the origin of the microorganisms applied as bioremediants (Khatik et al., 2006, Thakur et al., 2010, Uike et al., 2013, Keram et al., 2014 and Thakur et al., 2022).

Intrinsic bioremediation

This type of in situ bioremediation is carried out without direct microbial amendment and through intermediation in ecological conditions of the contaminated region and the fortification of the natural populations and the metabolic activities of indigenous or naturally existing micro-fauna by improving nutritional and ventilation conditions.

Engineered in situ bioremediation

This type of bioremediation is performed through the introduction of certain microorganisms to a contamination site. As the conditions of contamination sites are most often unfavourable for the establishment and bioactivity of the exogenously amended microorganisms, therefore here like intrinsic bioremediation, the environment is modified in away so that improved physico-chemical conditions are provided. Oxygen, electron acceptors, and nutrients (for example nitrogen and phosphorus) are required to enhance microbial growth (Dubey et al., 2016, Khandagle et al., 2020, Bairwa et al., 2020 and Tiwari et al., 2024).

Ex-Situ Bioremediation

The process of bioremediation here takes place somewhere out from contamination site, and therefore requires transportation of contaminated soil or pumping of groundwater to the site of bioremediation. This technique has more disadvantages than advantages. Depending on the state of the contaminant in the step



of bioremediation, ex-situ bioremediation is classified as:

Solid phase system (including land treatment and soil piles)

The system issued in order to bioremediate organic wastes and problematic domestic and industrial wastes, sewage sludge, and municipal solid wastes. Solid-phase soil

bioremediation includes three processes including land-farming, soil biopiling, and composting.

Slurry phase systems (including solid–liquid suspensions in bioreactors) Slurry phase bioremediation is a relatively more rapid process compared to the other treatment processes.

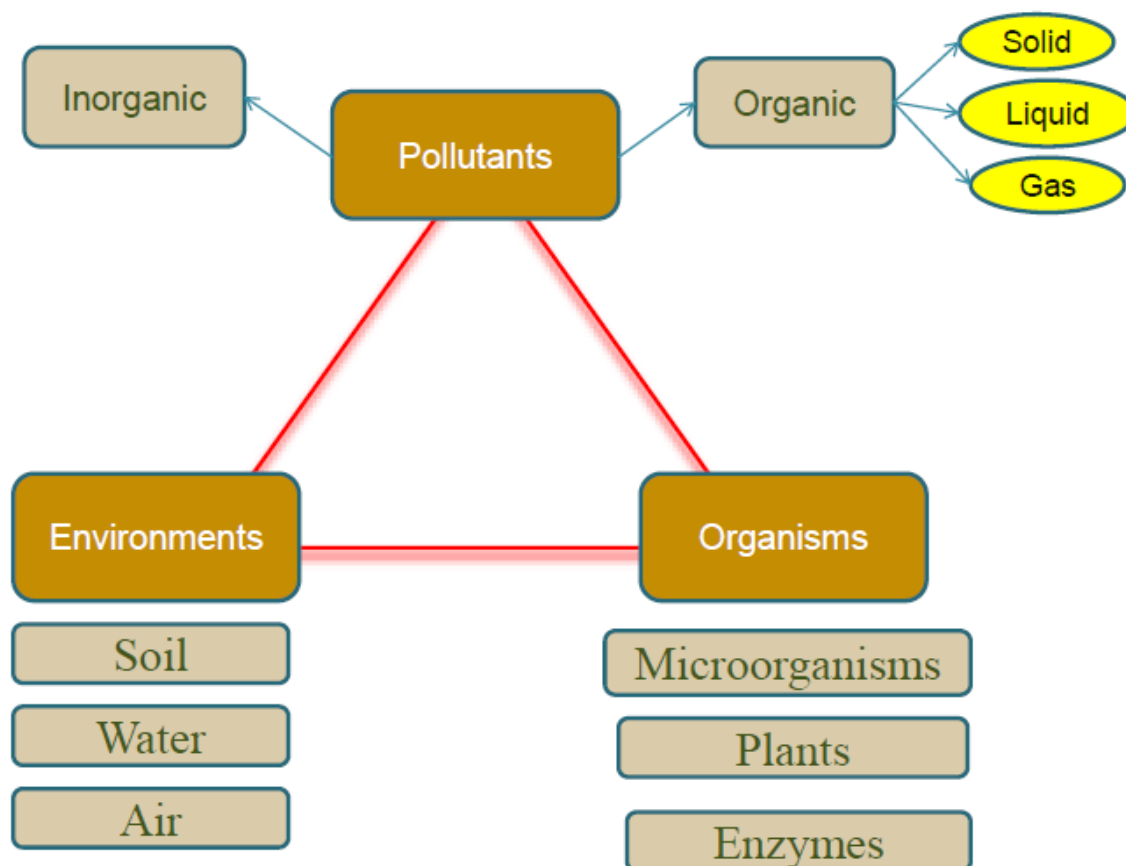


Fig. 1: Bioremediation is a triple-corners process

Bioremediation Techniques

There are several bioremediation techniques, some of them have been listed as follows:

Bio-augmentation

The addition of bacterial cultures to a contaminated medium used frequently in In-situ processes. Two factors limit the use of added microbial cultures in a land treatment unit: (a) non-indigenous cultures

rarely compete well enough with an indigenous population to develop and sustain useful population levels and (b) most soils with long-term exposure to biodegradable waste have indigenous microorganisms that are effective degraders if the land treatment unit is well managed.

Bio-filters



The use of microbial stripping columns used to treat air emissions.

Bioreactors

The use of biological processes in a contained area or reactor for biological treatment of relatively small amounts of waste. This method is used to treat slurries or liquids. Slurry reactors or aqueous reactors are used for ex situ treatment of contaminated soil and water pumped up from a contaminated plume. Bioremediation in reactors involves the processing of contaminated solid material (soil, sediment, sludge) or water through an engineered containment system. A slurry bioreactor may be defined as a containment vessel and apparatus used to create a three-phase (solid, liquid, and gas) mixing condition to increase the bioremediation rate of soil-bound and water-soluble pollutants as a water slurry of the contaminated soil and biomass (usually indigenous microorganisms) capable of degrading target contaminants.

Bio-stimulation

The stimulation of the indigenous microbial populations in soils and/or groundwater. This process may be done either in situ or ex situ.

Bio-venting

The process of drawing oxygen through the contaminated medium to stimulate microbial growth and activity. Bio-venting is the most common in situ treatment and involves supplying air and nutrients through wells to contaminated soil to stimulate the indigenous bacteria. Bio-venting employs low airflow rates and provides only the amount of oxygen necessary for the biodegradation while minimizing volatilization and release of contaminants to the atmosphere.

Composting

An aerobic and thermo-phillic process that mixes contaminated soil with a bulking agent. Composting may be performed using static piles, aerated piles, or continuously fed reactors. Composting is a technique that involves combining contaminated soil with non-hazardous organic amendments such as manure or agricultural wastes. The presence of these organic materials supports the development of a rich microbial population and elevated temperature characteristic of composting (Sahu et al., 2009, Kulhare et al., 2012, Kumar et al., 2021 and Thakur et al., 2023).

Land farming/Land Treatment/Prepared Bed Bioreactors

Solid phase treatment system for contaminated soil that may be applied as an in situ process or ex situ in a soil treatment cell. Land farming is a simple bioremediation technique in which contaminated soil is excavated and spread over a prepared bed and periodically tilled until pollutants are degraded. The goal is to stimulate indigenous bio-degradative microorganisms and facilitate their aerobic degradation of contaminants. In general, the practice is limited to the treatment of superficial 10–35 cm of soil.

Bio-piling

Bio-piles are a hybrid of land farming and composting. Essentially, engineered cells are constructed as aerated composted piles. Adding compost to contaminated soil enhances bioremediation because of the structure of the organic compost matrix.

Phytoremediation

Phytoremediation deals with the clean-up of organic pollutants and heavy metal contaminants using plants and rhizospheric



microorganisms. It is inexpensive, eco-friendly and an efficient means of restoration of polluted environments especially those that of heavy metals. Nonetheless, the level of soil contamination, the quantity of metal contaminant in the soil, as well as the ability of plants to aggressively take up metals from the soil, determine the success of phytoremediation at any polluted site.

Plants utilized in phytoremediation are the hyper-accumulators with very high heavy metal accumulation potential and little biomass efficiency, and non-hyper-accumulators, which possess lesser extraction capacity than hyper-accumulators, but whose total biomass yield is substantially higher and are fast-growing species (Fig. 2).

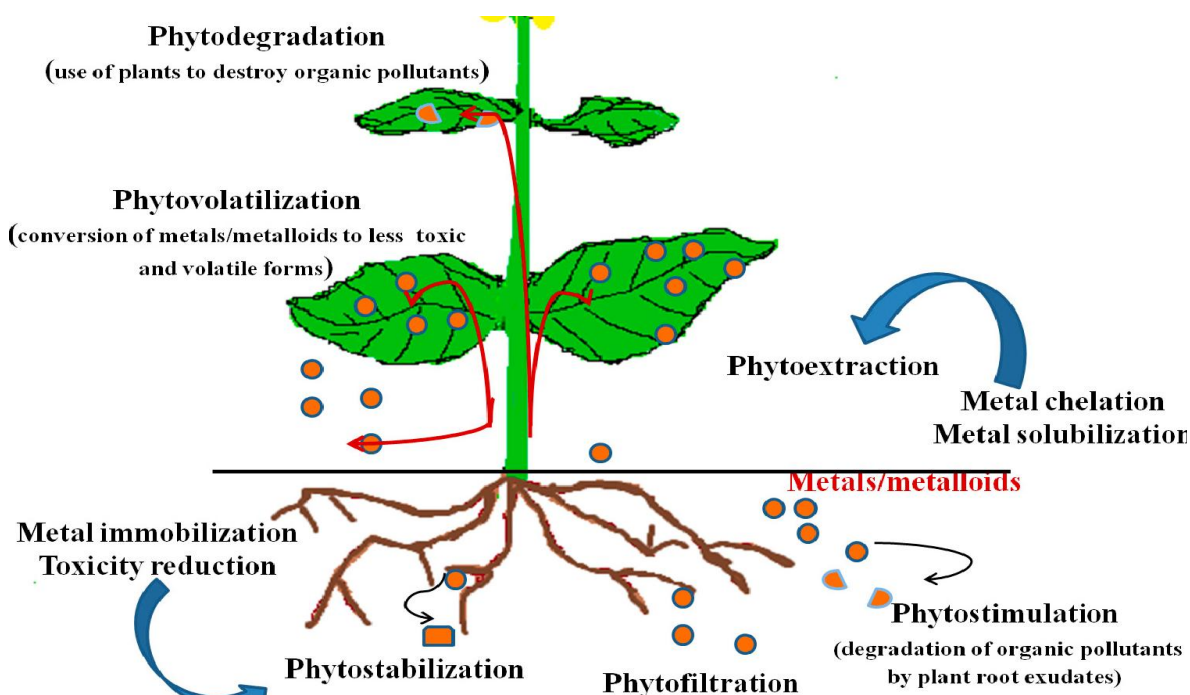


Fig. 2: Processes involved in phytoremediation

Advantages of bioremediation

- Bioremediation is a natural process and is therefore perceived by the public.
- Bioremediation is useful for the complete destruction of a wide variety of contaminants.
- Instead of transferring contaminants from one environmental medium to another, for example, from land to water or

air, the complete destruction of target pollutants is possible.

- Bioremediation can often be carried out on site, often without causing a major disruption of normal activities.
- Bioremediation can prove less expensive than other technologies that are used for clean-up of hazardous waste.

Disadvantages of bioremediation



- Bioremediation is limited to those compounds that are biodegradable. Not all compounds are susceptible to rapid and complete degradation.
- There are some concerns that the products of biodegradation may be more persistent or toxic than the parent compound.
- Biological processes are often highly specific to the microbial populations, suitable environmental growth conditions, and appropriate levels of nutrients and contaminants.
- It is difficult to extrapolate (deduce) from bench and pilot-scale studies to full-scale field operations.
- Bioremediation often takes longer than other treatment options.

Conclusion

The study underscores that the deliberate integration of multipurpose tree species (MPTS) into degraded and problematic lands provides a cost-effective, biologically sound, and sustainable pathway for soil restoration. Through enhanced nutrient cycling, nitrogen fixation, carbon sequestration, and biological remediation, MPTS improve soil structure, fertility, and productivity. The capacity of tree roots to stabilize soil and the potential of microbial-plant interactions in bioremediation make agroforestry systems vital for combating land degradation and promoting sustainable agriculture. The success of species such as *Acacia nilotica*, *Leucaena leucocephala*, *Gliricidia sepium*, and *Prosopis juliflora* in diverse agroecological zones demonstrates the scalability of this approach. Therefore,

MPTS-based agroforestry not only restores the ecological integrity of degraded soils but also strengthens rural livelihoods, ensuring a synergistic link between ecosystem resilience and socioeconomic development.

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The amazon rainforest: Importance, threats and conservation strategies

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The amazon rainforest- a global treasure

Amazon rainforest, a biodiversity hotspot, known for its incredible and rich biodiversity, is the largest tropical rainforest in the world, spans over 5.5 million square kilometers in South America with the majority located in Brazil. Stretching across nine countries (Brazil, Bolivia, Peru, Ecuador, Colombia, Venezuela, Guyana, Suriname and French Guiana), this region constitutes one of the most vital ecosystems of the planet (Butler, 2024).

Amazon rainforest holds immense importance as it supports varying biodiversity, helps in maintaining climate stability by sequestering carbon, ensures fresh water supply by annual precipitation, influences weather patterns, provides various economic resources and also has cultural and spiritual importance. Apart of this, it sustains life on the Earth as it absorbs carbon dioxide and releases 20% of the world's oxygen contributing to Earth's breathable air supply known as "the Lungs of the Earth" (Das and Saha, 2021). Approximately 40% of the world's remaining tropical rainforests are located within the Amazon region (Das and Saha, 2021). It provides invaluable ecosystem services to the Earth majorly:

Precipitation

The Amazon rainforest plays a crucial role in generating its own precipitation, with

transpiration processes accounting for approximately 50-75 % of this phenomenon. The trees release significant



Source: Unsplash/ Vlad Hilitanu

amounts of water vapor into the atmosphere through the process of transpiration. Although a considerable portion of this moisture precipitates locally as rain, some is transported by air currents to other regions of the continent. This phenomenon has been metaphorically described as "flying rivers" (Ferrante *et al.*, 2023).

Carbon storage

The Amazon rainforest, comprising around 390 billion trees, serves as a substantial reservoir of carbon, sequestering significant quantities within its foliage, branches, and trunks (Plotkin, 2020). A study published in *Global Change Biology* estimated that this forest sequesters approximately 86 billion tons of carbon, representing over one-third of the total carbon stored in tropical forests globally (Lorenz, 2010).

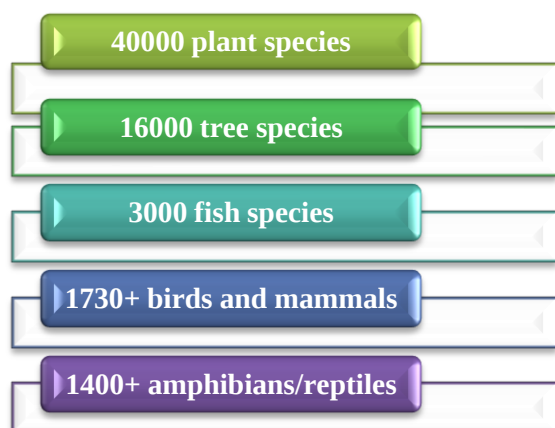
Biodiversity



The Amazon rainforest harbors a greater diversity of plant and animal species than any other terrestrial ecosystem globally, with estimates suggesting that approximately 30 % of the world's species reside within its confines. Beyond their inherent worth as living entities, these species hold significant potential for human benefit, particularly in the realms of medicine, nutrition, and various other products.

Local benefits

The Amazon Basin's significant population mostly relies on the ecosystem services provided by the forest. The river systems



Source: <https://worldrainforests.com/amazon>

serve as primary transportation routes, while logging and the harvesting of non-timber forest products constitute vital economic activities in numerous urban and rural areas (Ramirez-Gomez *et al.*, 2015). The rainforest plays a crucial role in mitigating, not entirely eliminating and fire risks but by improving air quality. Additionally, the fish populations in the tributaries of the Amazon are a critical source of protein for local communities. The annual flooding events contribute to the replenishment of nutrients in

floodplain regions, which are essential for agricultural practices (Tregidgo, 2016).

Structure of the amazon rainforest

The Amazon is Earth's largest rainforest with diverse ecosystems and vegetation types, which include rainforests, seasonal forests, deciduous forests, mangroves and savannas reflecting varying environmental conditions and consisting of nearly 30% of all known species on the Earth. In addition to rich fauna, it hosts approximately about 40,000-80,000 floral species many of which are still undiscovered holding medicinal potential. The Amazon River is the second-longest river in the world after the Nile which influences the forest's lifeline.

Major keystone species:

The Amazon rainforest serves as a habitat for a greater diversity of flora and fauna than any other terrestrial ecosystem globally. The keystone species significantly influence the forest and helps to maintain the ecological balance and ecosystem health. Different kinds of keystone species form a unique ecosystem in the amazon rainforest like predator keystone species control the population of other species which impact the food chain whereas ecosystem engineer keystone species help to create, destroy and alter habitats and mutualists are those that interact for mutual benefits. Among the forest inhabitants, there is plethora of well-known creatures which are becoming endangered due to habitat loss, over-exploitation, climate change, etc. that needs global concern and international conservation efforts to preserve biodiversity from extinction.



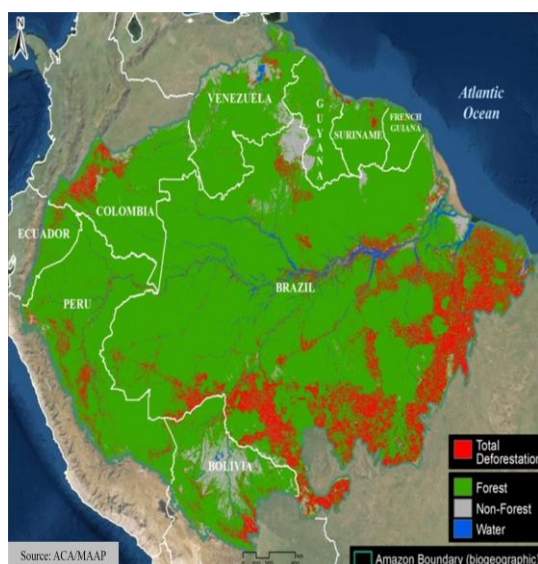
Keystone species of the Amazon rainforest

Predators	Ecosystem Engineers	Mutualists
Jaguar (<i>Panthera onca</i>)	Leafcutter Ants (<i>Atta</i> and <i>Acromyrmex</i> spp.)	Brazil nut (<i>Bertholletia excels</i>) and Agouti (<i>Dasyprocta</i> spp.)
Harpy Eagle (<i>Harpia harpyja</i>)	Giant Otters (<i>Pteronura brasiliensis</i>)	Fig tree (<i>Ficus</i> spp.) and Fig wasps
Green Anaconda (<i>Eunectes murinus</i>)	Bees (<i>Melipona</i> spp.)	Howler Monkeys (<i>Alouatta</i> spp.) and Fruit trees
Black Caiman (<i>Melanosuchus niger</i>)	Capybara (<i>Hydrochoerus hydrochaeris</i>)	Orchid bees (<i>Euglossini</i> bees) and Orchids
Piranhas (<i>Pygocentrus nattereri</i>),	Giant Armadillo (<i>Priodontes maximus</i>)	Ceiba tree (<i>Ceiba patendra</i>) and Bats
Amazon River Dolphin (<i>Inia geoffrensis</i>)	Bromeliads	Acacia trees and Ants (<i>Pseudomyrmex</i> spp.)

The growing threat - tipping points of amazon

Deforestation and habitat destruction

It has been recorded as one of the major cause for the depletion of the Amazon forest which is accelerating at an alarming rate. Due to deforestation driven by



logging, mining and large-scale agriculture, it releases significant amounts of carbon posing several consequences (Kalamandeen *et al.*, 2018). Deforestation in turn causes destruction of wildlife

habitat. Each year, extensive areas of forest are destroyed, endangering wildlife and contributing millions of tons of carbon emissions into the atmosphere. Satellite images have shown dramatic losses in the forest cover (Butler, 2024).

Researchers warn and raise concern that if deforestation continues at its current rate, the Amazon could reach a point where it can no longer sustain itself leading to “dieback”. Large parts of the forest would dry out, transforming into savannah-like environment (savannization) and further accelerating climate change.

Global climate change

Climate change alters the rainfall patterns, leading to more frequent and severe droughts. The worst drought in the Amazon occurred in 2005. Remote towns were cut off when rivers dried up, and trade came to a complete halt. Scientists noticed an apparent relationship between precipitation in the Amazon and sea surface temperatures in the Atlantic Ocean during the drought.

Illegal activities



Illegal activities like mining, selective logging and clear-cutting disrupt ecosystem causing destruction of wildlife. Wildlife trafficking, illegal hunting and poaching also threatens biodiversity at a greater extent.

Fire

Due to changing climate, fires have also plagued around destroying ecosystem and endangering wildlife. High temperatures dry out the rainforest making it more susceptible to fire. According to Rhett A. Bulter (2019), over 100 million metric tons of carbon was released into the atmosphere as thousands of square kilometers of land burnt for months at a time.

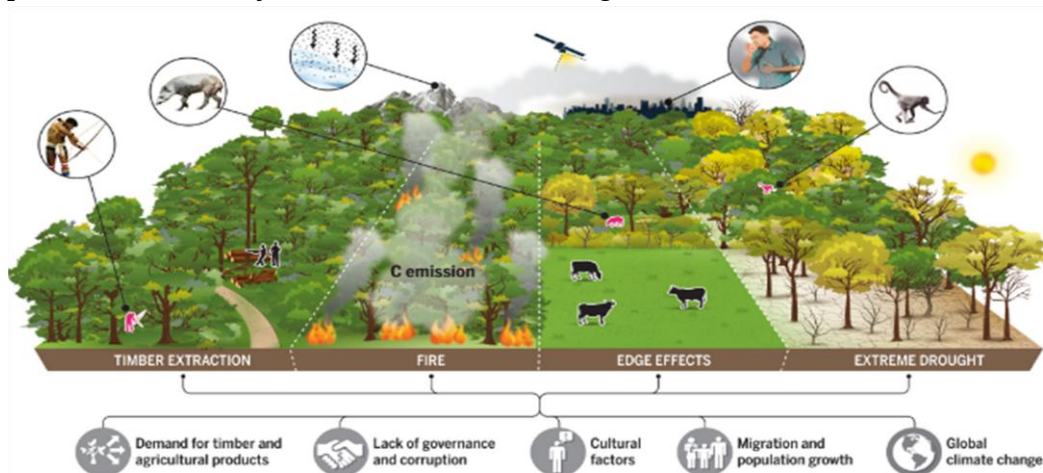
Indigenous rights violation

Land is crucial for social identity and wellbeing, as it validates cultural identity and provides autonomy for collective

decision-making. As indigenous tribes remain isolated from the outer world, they are often forced to leave their land due to lack of governance and corruption. Therefore, indigenous communities due to their rights violation are struggling for their survival. Owing to this, they may lose their cultural identity and traditional way of living.

Over-exploitation of resources

Over-exploitation of resources by indigenous communities to meet their basic needs including overfishing, overhunting, and over-harvesting of forest products deplete natural resources. Clear-cutting often due to large-scale deforestation for timber extraction and meeting needs of increasing population by converting forests to pastures or agricultural lands causes' destruction.



(Source: Lapola *et al.*, 2023)

Tipping points are exacerbated due to increased deforestation, forest fires and other threats but lack of quantification pushing closer to a critical threshold level which might lead to global warming acceleration, extreme biodiversity loss, disruption of rainfall patterns, regional droughts, habitat fragmentation and impact on indigenous communities (Nobre and Borma, 2009). In recent decades,

heightened climatic variability has led to the degradation of approximately 2.5 million square kilometers of forest area, primarily due to factors such as fire, edge effects, timber extraction, and extreme drought conditions (Lapola *et al.*, 2023).

Conservation strategies

The necessity for the preservation of Amazon is that this destruction has sparked outrage and concern across the



globe and it would be affecting human lives. Currently, the Amazon has already lost about 17% of its original forest cover (Flores *et al.*, 2024). Researchers report that changes in the Amazon forest are being driven by anthropogenic actions than naturally occurring environmental changes of the past. To prevent it from reaching its catastrophic tipping point requires urgent global action to prevent collapsing.

Addressing deforestation and habitat destruction

Environmental activists and scientists have called for immediate action to halt deforestation and protect its vital resources. Amazon contains around 150-200 billion tons of carbon helping to stabilize regional and global climate by sustainable forest management, investment in reforestation efforts, rehabilitation and increased productivity of forested lands using improved technology by increasing awareness about sustainable consumption choices.

Mitigating climate change and fire hazards

Global climate action and international efforts to reduce greenhouse gas emissions can help in mitigation of climate change. Controlled burning, early detection of fire, preventing large scale wildfires and involving local communities in fire prevention and management can control fire hazards.

Combating illegal activities and protecting indigenous rights

Conservation projects aim to restore socio-natural relations, combat illegal activities and protect indigenous rights. Initiatives including expansion of protected areas, land reform policy and law enforcement could be taken to conserve the ecosystem

(Butler, 2019). Displacement of indigenous communities leaves them vulnerable but they are the most knowledgeable conservationists, preserving the last remaining intact forests and addressing the climate crisis (Garnett *et al.*, 2018). They have nurtured their forests for millennia, preserving 80% of the world's biodiversity (Sobrevilla, 2008).

Overcoming resource exploitation

Promotions of sustainable resource management by sustainable fishing, hunting and gathering practices, community-based resource management reduces demand for over-exploitation and obtain ecosystem services. Besides this, sustainable agricultural and agroforestry practices and ecotourism could offer alternatives benefitting both the environment and local communities (Porro *et al.*, 2012).

Conclusion

Amazon's faith is tied to our own fate as it is just more than a forest but it serves as the essential support system for the entire planet. So, its protection and conservation is a human need and not just an environmental issue. As climate change becomes an ever-growing threat, there is an urgent need to preserve and conserve wildlife.

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Crepidium acuminatum: Insights into a lesser known medicinal orchid

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Introduction

Orchidaceae is among the major family within the angiosperms and is represented by 736 genera and 28000 species (Christenhusz and Byng, 2016). Orchids belong to diverse group of flowering plants spread across the globe from the tropical region to alpine region. There is wide range application of orchids in cosmetic, pharmaceutical and perfumery industry. The application of orchids in phytomedicine has long standing history. Over centuries, various species of orchids have been utilized as ailment for curing of various disorders such as infections, pains and inflammatory diseases. Advancement in medicinal orchid research has led to the identification of different bioactive compounds which have revealed ability in the management of prolonged diseases. The secondary metabolites isolated from orchids have revealed aptitude as anti-ageing, anti-tumour, anti-microbial, anti-carcinogenic, anti-rheumatic, anti-convulsive, anti-inflammatory, hypoglycemic, neuroprotective and wound healing properties (Hossain, 2011; Pant, 2013). *Crepidium acuminatum* (D. Don) Szlach commonly known as jeevak is a terrestrial orchid belongs to the

Orchidaceae family. It is an endangered orchid and has its distribution from subtropical to temperate region of the Himalayas in India at an altitude of 1200-2100 m amsl. The plant is 30 cm in height and comprises of pseudobulb and fibrous roots. The numbers of leaves are 3-4 with length of 5-15 cm, simple, alternate, ovate-lanceolate and acute at the tip, along with a sheathing support. The flower colour is yellow-greenish with tinge of purple colour in the centre. This medicinal orchid is commonly renowned for its remedial importance in ayurveda and modern science. It is one of the important constituent of Astavarga and herbal formulations such as "Chyawanprash" (Balakrishna et al., 2012). It has various beneficial health effects such as enducing fertility, reducing burning sensation, internal and external haemorrhage, fever, bleeding, immunity enhancing, treating tuberculosis, dysentery, and diarrhoea (Chinmay et al., 2011; Balakrishna et al., 2012; Sharma et al., 2014).

Distribution of *C. acuminatum*

Globally, *C. acuminatum* is distributed from the southern Himalayas to Myanmar, Thailand, Southern China (Xizang, Yunnan, Guizhou, Guangdong and



Taiwan), Indo-china, Philippines and Australia at an altitude range of 300-2100 m (Teoh, 2016). In India, it is distributed from subtropical to temperate Himalayan

Morphology of *C. acuminatum*

Habit

It is erect; small with the stem consists of aerial flowering axis and swollen stem at the base similar to rhizome like structure bearing nodes and internodes ascending from the base of mother rhizome. Mother rhizome remains erect and so before becoming horizontal and produces two to four pseudobulbs and swollen stem at base produce one daughter rhizome. The pseudobulbs once separated produce new plants throughout upcoming growth phase (Sharma et al., 2014).

General Morphology

It is terrestrial herb of 16-36 cm height with glabrous and sheathed stem. Leaves are 3-4 in number with leaf size (5.5-13×2.5-7cm), ovate to lanceolate, acuminate, margins undulate and petiolate. Inflorescence type is raceme and laxly multi-flowered, 12-27 cm long peduncle, rachis is ribbed with 4.5-9 cm length; abundant, very minute and powdery (Sharma et al., 2014).

Ethnobotanical uses of *C. acuminatum*

In Nagaland, people utilize rhizome/pseudobulb decoction of this plant in curing diathesis, bleeding, and fever and also act as a spermopiatic (Uma et al., 2015). Pseudobulbs in fresh form are utilized in treatment of phthisis and bleeding diathesis and are utilized

region which includes Himachal Pradesh, Arunachal Pradesh, Meghalaya, Assam, Nagaland, Manipur, Mizoram and Tripura (Balkrishna et al., 2012; Vij et al., 2013).

ovary is pedicellate with 5-8 mm length. Flowers are yellow green tinged with purple, 1-1.3 cm in length, minute floral bracts of 3 mm length. Sepals are free and sub-similar with recurved margins; dorsal sepal linear-oblong, subacute (7.2 × 1.8 mm), revolute margin, 3 veined; lateral sepals are broadly oblong to obtuse (5.5-6 × 1.6-1.8 mm). Petals are linear, obtuse, margins recurved (5-6 × 1-1.2 mm). Lip is narrowly ovate to sagittate (6-7 × 4-5 mm) base 2-lobed, straight and parallel, apex flat, incurved at the notch (Ahmed and Dhiman, 2022). Column is 1-1.1 mm in length, fleshy, anther ovate with 4 pollinia, viscidium minute. Pseudobulbs are ovoid or oblong, tufted with size (2-5 × 1-1.5 cm). Roots are clustered at the bottom of pseudobulb with 1-2 mm thickness. Fruit type is capsule, fusiform, ribbed, single cylindrical capsule per flower. Unripe fruits are green in colour and become pale brownish on ripening. Seeds are externally as a paste in treating rheumatism and insect bites with other plants (Chinmay et al., 2011). *C. acuminatum* is frequently adulterated with roots of *Withania somnifera*, *Lillium wallichianum*, *Ipomoea digitata*, *Pueraria tuberosa* and *Chlorophytum borivilianum* owing to its high demand and inadequate accessibility.

Table 1: Traditional uses of *Crepidium acuminatum*

Sr. No.	Scientific name	Local name	Parts used	Traditional uses	Region
1.	<i>Crepidium</i>	Gachno,	Pseudobulb,	Powder of pseudobulb	Makwanpur



	<i>acuminatum</i>	Gavndamala	Root	& roots used against burning sensations, fever and bleeding.	(Nepal)
2.	<i>Crepidium acuminatum</i>	Jeevak	Leaf	Leaf juice mixed with honey given to cure bronchitis.	Mandi (Himachal Pradesh)
3.	<i>Crepidium acuminatum</i>	Jeevak	Pseudobulb	Pseudobulb extract is used as a tonic for enhancing sperm formation besides curing tuberculosis.	-
4.	<i>Crepidium acuminatum</i>	Jeevak	Pseudobulb	Coolant, febrifuge & spermopoietic, sweet, cold in potency, which is known to pacify Vata & aggravates Kapha & also cures bleeding disthesis, burning sensation, fever, phthisis	-
5.	<i>Crepidium acuminatum</i>	Jeevak	Pseudobulb	Intake of pseudobulb powder promotes lactation	-
6.	<i>Crepidium acuminatum</i>		Pseudobulb	1 g of powdered <i>C. acuminatum</i> pseudobulb is mixed with the powdered <i>M. monophyllos</i> (syn. <i>M. muscifera</i>) pseudobulb, <i>Lilium polyphyllum</i> bulb, <i>Fritillaria roylei</i> bulb and <i>Asparagus racemosus</i> . This is consumed in the morning.	-



Pharmacological activities of *C. acuminatum*

Pseudobulb is Sweet, aphrodisiac, haemostatic, antidiarrhoeal, styptic, antidysentric, febrifuge, cooling and tonic. It is useful in sterility, vitiated conditions of pitta and vata, semen related weakness, internal and external hemorrhages, dysentery, fever, emaciation, burning sensation and general debility.

Jivaniya (Vitality promoter)

This medicinal plant is vitality promoter; maintain the balance between three doshas i.e. Vata, Pitta and Kapha. It enhances the energy, body strength, skin glow and other properties of the body.

Bramhaniya (Body mass promoter)

This medicinal plant is body mass promoter. It is described within the Bramhaniya varga.

Ayushya (Longevity)

This medicinal plant mitigates the disorder of the body and specifically alleviates Tridosaja disorder in the body to increase the longevity and slow down the process of aging.

Antioxidant activity: Pseudo bulb extract of *Crepidium acuminatum* shows antioxidant activity.

Antifungal and Antibacterial Activity:

Extract of *Crepidium acuminatum* shows antifungal and antibacterial activities.

Ayurvedic formulations of *Crepidium acuminatum*

Mahamayur Ghrita

It is processed with Jivaka and other herbs is useful in Rasaraktadi dhatugat vikara, shrotadi indriya vikara (sensory organ disorders), svarabhansa (Aphesia), asthma, cough, facial paralysis, vaginal disorders, blood disorders and semen related problems.

Intake of powder prepared from jivaka and other herbs mixed with an appropriate quantity of honey and crystal sugar is useful in cough and cardiac diseases.

Vacadi Taila

It is processed with jivaka and other herbs used as anuvasana vasti. It is beneficial for gulma, distention, vata associated disorders and urinary incontinence.

Jivaniya Ghrita

It is processed with jivaka is useful for the whole body vitiated with gout and vata associated disorders.

Citrakadi Taila

It is processed with jivaka and other herbs is useful in vata associated disorders, sciatica, limping, kyphosis, gout and urinary disorders.

Mahapadma Taila

It is processed with Jivaka and other herbs is useful in gout and fever.

Intake of Ghrita processed with Devadaru, Kakoli, Jivaka and other medicinal herbs given in proper dose is useful in child emaciation.

Himavana Agada

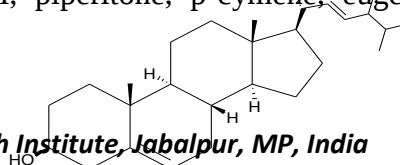
It is prepared with the powder of pancavalkala, jivaka and other herbs mixed with honey to make a paste and external application of this paste on snake bite reduces the toxicity. It also alleviates other symptoms like edema, erysipelas, boils, fever and burning sensation.

Asthapana vasti

It is processed with Jivaka and other medicinal herbs is useful in treating gulma, metrorrhagia, anaemia, malaria.

Phytoconstituents in *C. acuminatum*

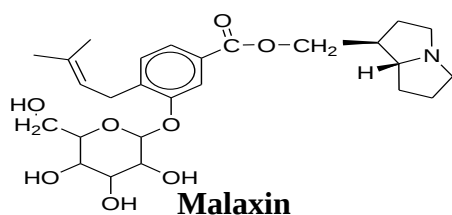
The rhizomes and pseudobulbs of this plant contains β -sitosterol, stigmasterol, malaxin, grandifoline, gigantol, batatasin III, piperitone, p-cymene, eugenol, cetyl



alcohol, coline, 1,8-cineole, citronellal,

limonene.

Stigmasterol



β - sitosterol

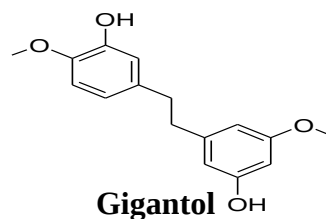


Fig. 2: Major Phytoconstituents in *C. acuminatum*

Conservation Status of *C. acuminatum*

On the basis of habitat & species distribution data, Conservation Assessment and Management Plan (CAMP) - World Wide Fund for Nature has categorized *Crepidium acuminatum* as “vulnerable” whereas the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) has included *Crepidium acuminatum* within the CITES Appendix II of endangered species for ensuring its conservation.

Conclusion

Crepidium acuminatum is a phytochemically enriched yet less explored medicinal orchid with important ethnobotanical significance. Its distinctive phytochemical profile, traditional medicinal uses and ecological importance underscores the need for scientific research on its bioactive compounds, pharmacological potential and utilization in sustainable manner. Population of this important medicinal orchid is decreasing due to increased collection from the wild. Conservation and cultivation-based strategies with scientific advancement are essential for safeguarding this important species.

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Kalihari (*Gloriosa superba* L.): An endangered medicinal flame of nature

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Introduction

Nature has always been considered the greatest healer for humankind. Since civilization began, plants have not only provided food, but also medicine, clothing and shelter. Among the numerous medicinal plants, few are as striking as *Gloriosa superba* L. (Family: Colchicaceae), popularly known as Kalihari, Glory Lily, Flame Lily, or Agnisikha. It is recognized for its extremely attractive, flowering beauty and medicinal properties. *Gloriosa superba* L. is a herbaceous, climbing, perennial plant native to tropical Africa, but it is now also found in tropical Asia (India, Sri Lanka, Bangladesh, Malaysia and Myanmar) (Kiros et al. 2023). In India, it is restricted largely to Maharashtra, Karnataka, Kerala, Goa, and Tamil Nadu. Kalihari can thrive from the southern plains of India and as high as elevations of 2,100 m in the Himalayan foothills in areas of Himachal Pradesh, Jammu & Kashmir and Uttar Pradesh (Mahajan et al. 2024). The flowers of Kalihari are easily recognized by their flames or brilliant colours, with spiky petals curling backward or spreading out in all directions looking like flickering tongues of fire, hence the name Flame Lily. Kalihari is important symbolically for culture, as it is the national flower of

Zimbabwe and the official state flower of Tamil Nadu, India.

Phytochemically, it is famous because of its toxic alkaloid, colchicine, which is found in the whole plant, making this plant toxic in significant quantities. Colchicine is an important bioactive product that is being used by modern medicine to treat gout and cancer and that also used in cytogenetics as a primary experimental compound because it is a mitotic inhibitor in the process of inducing polyploidy. In the 1980s indiscriminate harvesting of tubers from local communities and pharmaceutical companies extracted from its natural habitat as ultimately brought it to near extinction due to their harvesting of the plant. As a result, *G. superba* has been declared "endangered" by IUCN Red Data Book (Padmapriya et al. 2015). Beyond any overexploitation, also impacted by natural limitations with low seed germination with poorly viable seeds is also causing significant declines. Cytogenetically, the species is predominantly diploid with its chromosome number of $2n=22$ (Vijayavalli and Mathew, 1990) with an aneuploid form of $2n=21$ confirmed (Vishwakarma and Tarar, 1989). Because there is an increasing demand for colchicine in the pharmaceutical industry



and with wild populations of Kalihari falling, it is now considered a high value cash crop. Sustainable utilization of Kalihari requires not only identification and screening for elite germplasm with the highest possible levels of colchicine but also evaluation of other methods of enhanced colchicine production. Consequently, conservation, cultivation and biotechnological strategies are significant priorities in the current research agenda involving this valuable medicine.

Botanical Description

Gloriosa superba is a perennial, climbing, monocot plant and is commonly found in India; this plant has hollow stems that can be as long as

6 m. It grows from underground tubers and it often produces two tubers that are shaped like a V. The leaves are sessile leaves, ovate-lanceolate shaped and end in tendril-like projections that the plant uses to climb up a surface. The flowers are produced from August-October and are large and attractive; while flowering they display a bright yellow, slowly changing to orange with scarlet red in the final stages of flowering, with wavy edges (**Figure 1**). The fruit is a three-celled oblong capsule with sub-globose-shaped seeds and the seeds have a spongy, winged testa.



Figure 1: Kalihari showing lush green vines with vibrant red-yellow blooms and flowers

Cultivation of *Gloriosa superba*

Kalihari thrives in red loamy soils with a pH of 6.0–7.0 and hot humid tropical and subtropical climates, where it requires an annual rainfall of roughly 70 cm. Planting occurs during the June–July monsoon season. This species can be propagated by tubers in the soil, although seed is a supplementary contributor to a floricultural diversity. When planting, one must first mix into the soil about

10 tonnes of FYM/ha (farm yard manure). A furrow that is about 20 cm deep and at distance of 120–140 cm apart, is made and tubers (1,800–2,000 kg/ha) are planted 20 to 35 cm apart. After planting, irrigation is required, at intervals of five days until the plants are established and no irrigation is required once flowering commences. Weeding and manuring (250 kg/ha FYM, and 120:50:75 kg/ha NPK), is the current agronomic practice, with



half nitrogen to be the base, and full phosphorous and potash, the remainder of the nitrogen 2 months after planting. Organic manures, as well as bio-pesticides like neem, chitrakmool, dhatura and cow's urine, will market their medicinal value. For it to be valid, they need to find issues and if it is an issue, artificial pollination could increase yield. Pods collected will not be harvested until 170-180 days after planting whereas tubers should not be matured or harvested for 5-6 years. Shade drying is recommended after harvest to ensure there is a good concentration of alkaloids. Yields are low to begin with and increase as the crop is cared for and managed effectively.

Traditional medicine of Kalihari

Kalihari has been culturally and historically important for many years, especially in traditional medicine, as part of Ayurveda, Siddha and Unani systems. The drug has been used by traditional healers, in folk medicine and traditional knowledge, for varied conditions using almost all parts of the plant, including the tubers, seeds, leaves and flowers. Its use in traditional medicine is probably most notable in treating rheumatism and gout (Jana et al. 2011). The tubers have been greatly valued in folk medicine as treatment for chronic ulcers, hemorrhoids, leprosy, cancer, and as an inducer of labour pains (Budchart et al. 2017). Pharmacological evidence has provided support for the use of tubers as an abortifacient, anthelmintic, tonic and stomachic in smaller doses.

In the North-Eastern Indian region, the tubers are reputedly used as a tuber paste for the treatment of both gout and wounds and additionally as a bitter tonic for

various conditions including, antipyretic, expectorant, gastrointestinal irritant, purgative and stomachic. The Ayurvedic system considers the tuber to be useful to the body by restoring vitiated states of Kapha and Vata doshas (Kavina et al. 2011). The leaves also play a vital role in indigenous medicine. Leaf extracts mixed with sesame oil have been used topically to treat joints where arthritis has begun or that are afflicted by asthma. A combination of leaf extract and leaf juice has been used against lice and skin infections, and sap from leaf tips is used topically to treat pimples (Kavina et al. 2011). The seeds are a rich source of colchicine, a major reason that they are so valued in the world of herbal trade. Traditionally, seeds have been prescribed for cancer-related conditions (Shen et al. 2011). Colchicine is a drug that has been in clinical use for more than 200 years and is still useful against gout, which is a widespread affliction in many temperate areas of the world. Despite this immense value, it should be noted that Kalihari is highly toxic. By consuming the tuber wrongly, destines it to have fatal alkaloid contents (Dhanabalan et al. 2024). Its ability to function as a valuable healer and a dangerous poison makes it one of the most captivating medicinal plants in traditional medicinal applications.

Conclusion

Kalihari is an important medicinal plant with multiple possible therapeutic usages, mainly, gout and rheumatism and skin conditions. The medicinal properties of Kalihari are mainly attributed to the toxic compound colchicine, but its toxic potential should be acknowledged



along with its potential value as a cure. Therefore, this plant can be viewed as both a useful curative resource and a powerful poison, the latter not being a sole consideration in our modern healthcare system. Thus, it is needed to validate the use of any potential for curative uses with rigorous scientific scrutiny - for validation of use and regulation of use.

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