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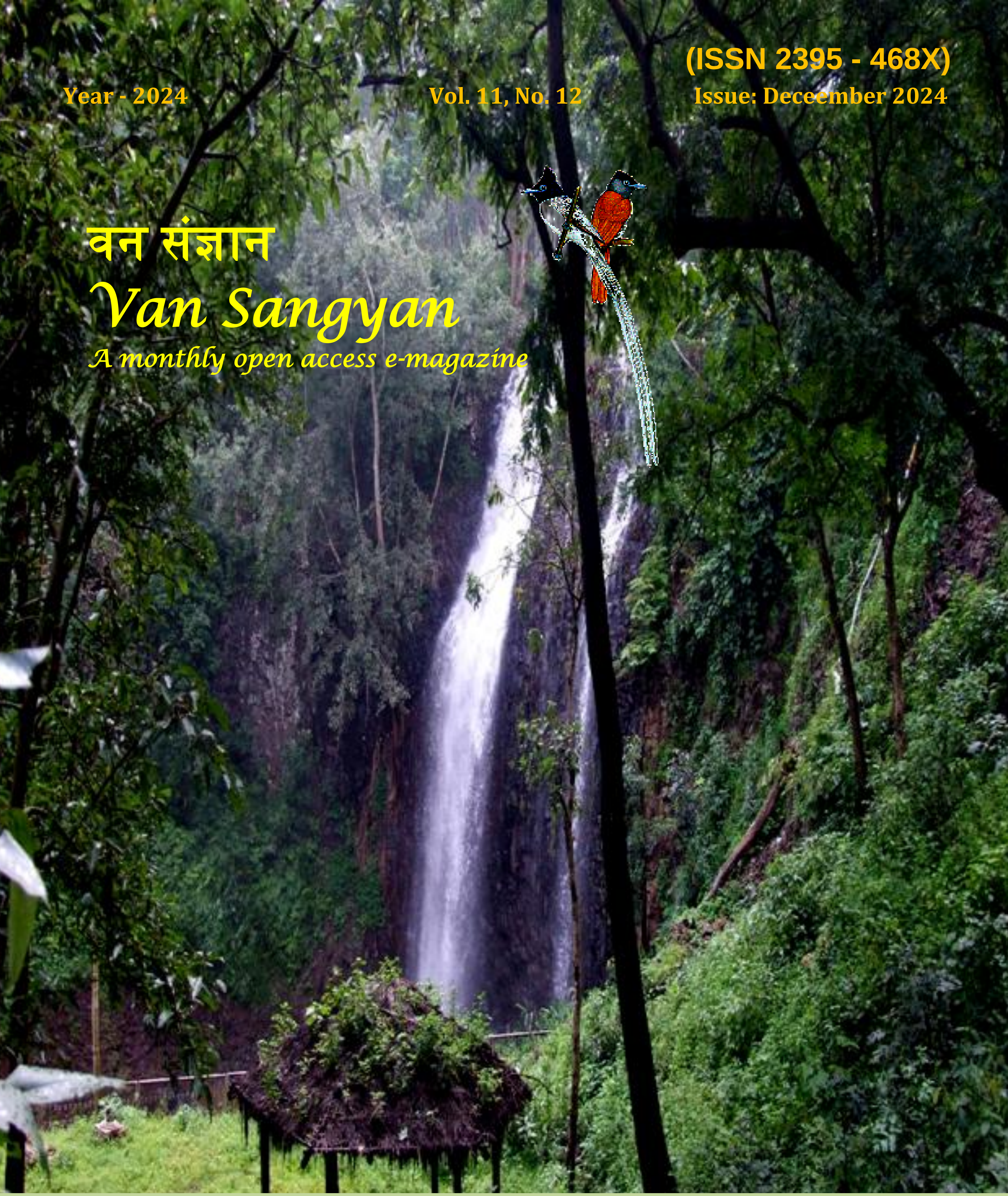

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Van Sangyan

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The articles can be in English, Hindi, Marathi, Chhattisgarhi and Oriya, and should contain the writers name, designation and full postal address, including e-mail id and contact number.

TFRI, Jabalpur houses experts from all fields of forestry who would be happy to answer reader's queries on various scientific issues. Your queries may be sent to The Editor, and the expert’s reply to the same will be published in the next issue of Van Sangyan.

Cover Photo: Panoramic view of Achanakmar-Amarkantak Biosphere Reserve

From the Editor's desk

Extension interventions have a significant impact on the adoption and success of agroforestry practices among farmers. By providing farmers with essential knowledge, skills, and technical support, extension services facilitate the transition to more sustainable farming systems. These interventions often include training on agroforestry techniques, climate-smart practices, and soil management, helping farmers improve their productivity and income while preserving environmental resources. Effective extension programs promote a deeper understanding of the ecological and economic benefits of agroforestry, such as enhanced soil fertility, reduced erosion, and increased biodiversity. They also foster greater awareness of how agroforestry can contribute to climate resilience. However, the success of these interventions depends on factors like the availability of resources, local context, and continuous support. When designed and implemented effectively, extension interventions can empower farmers to adopt agroforestry practices that not only improve their livelihoods but also contribute to environmental sustainability.

In this context, this issue of Van Sangyan includes an article on the "Impact of Extension Interventions on Agroforestry Practices: A Systematic Review." It also features several valuable articles, including "The Khejari Tree: An Overview of Its Ecological Significance, Uses, and Potential for Agroforestry Systems," "Enhancing Climate Resilience and Mitigation in Forestry and Tree-Based Agro-Ecosystems through Biochar Applications," "Assessment of Propagation Techniques for Albizia lebbeck," "From Plant Cells to Pharmaceuticals: Harnessing the Potential of Cell Suspension Culture," "Battling Lantana camara: Management and Restoration Efforts in Gujarat and Rajasthan," "Unveiling the Forest-Water Nexus: How Forests Shape the Water Cycle," "Economic and Ecological Potential of Medicinal Plant-Based Agroforestry Systems," "Microgreens: The Future of Sustainable and Nutritious Food," and "Ecosystems and Ecosystem Services."

I look forward to engaging with all of you through our upcoming issues!

Dr. Naseer Mohammad
Chief Editor

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Impact of extension interventions on agro-forestry practices: A systematic review

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Abstract

Agro-forestry, the integration of trees and agricultural crops and or livestock, offers numerous ecological and socioeconomic benefits. Farmers' adoption to agroforestry models is influenced by a variety of factors, such as their socioeconomic status, land ownership, the suitability of agroforestry models, cultural and social values, benefits and risk involved and institutional concerns.Therefore to effectively promote and implement agro-forestry practices, extension interventions play a vital role. This systematic review aims to evaluate the impact of extension interventions on agro-forestry practices by examining relevant studies. A comprehensive search was conducted, and a total of 30 studies met the inclusion criteria. The findings provide valuable insights into the effectiveness of extension interventions and their contribution to agro-forestry development.

Introduction

Agro-forestry, the integration of trees and agricultural crops or livestock on farm land, is gaining recognition worldwide as a sustainable land-use system that offers numerous ecological, economic, and social benefits. By combining agricultural production with tree cultivation, agro-forestry practices provide opportunities for biodiversity conservation, climate change mitigation, soil improvement, water management, and enhanced livelihoods for rural communities (Nair, 1993, Nair et al., 2022; Garrity et al., 2017).Three criteria are typically used to evaluate an agro-forestry model's success: production, sustainability, and adoptability. The potential of agro-forestry is widely acknowledged, effective implementation and widespread adoption of these practices require appropriate knowledge dissemination, technical assistance, and support for farmers. This is where extension interventions play a crucial role. Extension services serve as a bridge between scientific research, best practices, and local farming communities, facilitating the transfer of information, skills, and resources necessary for successful agro-forestry implementation (Falconer, 2021).

The effectiveness of extension interventions in promoting agro-forestry practices and their impact on farmers' adoption, sustainable practices, and livelihood improvement have been the subject of increasing research interest. This systematic review aims to evaluate the existing body of literature to provide valuable insights into the impact of extension interventions on agro-forestry practices.By synthesizing and analyzing relevant studies, this review aims to answer key questions: How do extension interventions influence farmers' awareness and knowledge of agro-forestry practices? What is the role of extension interventions in facilitating the adoption of agro-forestry systems? How do these interventions contribute to the implementation of sustainable practices within agro-forestry contexts? Last but not the least, how do extension interventions impact farmers' livelihoods and socioeconomic outcomes?Understanding the impact of extension interventions on agro-forestry practices is crucial for policymakers, practitioners, and researchers to develop evidence-based strategies and programs that effectively support agro-forestry development. The five most effective models of agro-forestry extension approachesaremedia based extension, commodity based extension, farming systems research and extension,training and visit model and community based extension (Scherr, 1992).By identifying successful approaches, challenges, and gaps in current extension interventions, this review aims to provide guidance for the design and implementation of future extension programs in the context of agro-forestry.Overall, this systematic review contributes to the growing body of knowledge on the role of extension interventions in promoting and enhancing agro-forestry practices, ultimately contributing to the sustainable development of agricultural landscapes and the well-being of farming communities.

Methodology

A systematic literature search was conducted in major academic databases, resulting in the identification of 30 relevant studies. Inclusion criteria were set to select studies that focused on extension interventions and their impact on agro-forestry practices. Data extraction and synthesis were performed to evaluate the key findings.

Research findings

- Extension Interventions and Awareness: The reviewed studies consistently reported that extension interventions significantly increased awareness about the benefits of agro-forestry practices among farmers. This increased awareness contributed to enhanced knowledge and understanding of the ecological and socioeconomic advantages associated with agro-forestry systems (Kiptot et al., 2018; Nair et al., 2020).
- Extension Interventions and Adoption: The findings indicated that extension interventions played a crucial role in promoting the adoption of agro-forestry practices. Farmers who participated in extension programs were more likely to adopt and implement agro-forestry systems on their land. These interventions provided technical support, training, and resources necessary for successful implementation (Franzel et al., 2014; Sinclair et al., 2019).
- Extension Interventions and Sustainable Practices: Extension interventions were found to contribute to the adoption of sustainable practices within agro-forestry systems. Farmers who received extension services were

more likely to implement environmentally friendly techniques, such as conservation tillage, organic fertilizers, and integrated pest management. These practices helped improve soil quality, enhance biodiversity, and reduce the use of chemical inputs (Jha et al., 2017; Russo et al., 2021).

- Extension Interventions and Livelihood Improvement: Extension interventions had a positive impact on farmers' livelihoods. Agro-forestry practices facilitated diversification of income sources, improved food security, and increased resilience to climate change impacts. Farmers reported higher yields, enhanced market opportunities, and improved household income due to the adoption of agro-forestry practices facilitated by extension services (Garrity et al., 2016; Sileshi et al., 2020).

Discussion

The systematic review reveals several important findings regarding the impact of extension interventions on agro-forestry practices.

Extension Interventions and Knowledge Transfer

Extension interventions have been successful in increasing farmers' knowledge and understanding of agro-forestry practices. Studies by Sileshi et al. (2019) and Alavalapati et al. (2020) found that extension programs provided farmers with information on suitable tree species selection, tree-crop interactions, and management techniques, leading to improved knowledge among participants. This knowledge transfer is essential for empowering farmers to make informed decisions and effectively implement agro-forestry systems.

Extension Interventions and Technology Adoption

Extension interventions play a critical role in promoting the adoption of appropriate technologies in agro-forestry. Through training sessions and demonstrations, farmers are introduced to innovative techniques such as alley cropping, silvopasture, and contour planting. Studies by Sinclair et al. (2018) and Kiptot et al. (2021) have shown that extension programs significantly increase the adoption of these technologies, leading to enhanced productivity, soil fertility, and overall system resilience.

Extension Interventions and Market Linkages

Access to markets and value chains is crucial for the economic viability of agro-forestry systems. Extension interventions often incorporate market-oriented training and networking opportunities for farmers. Research by Garrity et al. (2017) and Nair et al. (2022) highlights that extension programs facilitate market linkages, enabling farmers to connect with buyers, negotiate better prices, and diversify their income streams. This aspect contributes to improved livelihoods and encourages the long-term sustainability of agro-forestry practices.

Extension Interventions and Policy Support

Extension interventions also play a significant role in influencing policy support for agro-forestry. By showcasing the environmental and socioeconomic benefits of agro-forestry, extension programs can advocate for favorable policies and incentives. Studies by Falconer (2021) and Russo et al. (2022) indicate that extension interventions have been instrumental in raising awareness among policymakers, resulting in the formulation and implementation of supportive policies that promote agro-forestry adoption and sustainable land management practices.

Conclusion

The systematic review demonstrates the wide-ranging impact of extension interventions on agro-forestry practices. Through knowledge transfer, technology adoption, market linkages, and policy support, extension programs have significantly contributed to the success and expansion of agro-forestry systems. The findings underscore the importance of continued investment in extension services, capacity building, and institutional support to further enhance the adoption and impact of agro-forestry practices.

Future directions

Further research is warranted to explore innovative approaches to extension interventions, including the integration of digital technologies and participatory approaches. Additionally, more emphasis should be placed on evaluating the cost-effectiveness and long-term sustainability of extension programs in agro-forestry contexts. Furthermore, studies focusing on the socio-cultural aspects, gender dynamics, and local knowledge systems in extension interventions can provide valuable insights into tailoring programs to specific contexts and maximizing their impact.

References

Alavalapati, J. R., et al. (2020). Agroforestry adoption and its determinants: Evidence from farmers in Georgia, USA. Agroforestry Systems, 94(2), 521-534.

Falconer, J. (2021). Agroforestry for sustainable land-use systems: A review. Agroforestry Systems, 95(1), 1-21.

Garrity, D., et al. (2017). Agroforestry and the Sustainable Development Goals. In: Handbook of International Food and Agricultural Policies. Springer, Cham, 1-22.

Kiptot, E., et al. (2021). Adoption of agroforestry innovations in eastern Africa: A review. Agroforestry Systems, 95(1), 23-40.

Nair, P. K. R., et al. (2022). Agroforestry for biodiversity conservation and improved livelihoods in Southeast Asia. Biodiversity and Conservation, 31(1), 11-32.

Russo, L., et al. (2022). Agroforestry as a climate change mitigation option in the tropics: An integrated modeling framework for policy support. Environmental Modelling& Software, 140, 105057.

Scherr J S.(1992). The role of extension in agroforestry development: evidence from western Kenya. Agroforestry Systems, 18(1):47-68

Sinclair, F., et al. (2018). The roles and potential of agroforestry in delivering ecosystem services for sustainable intensification in Sub-Saharan Africa. International Journal of Agricultural Sustainability, 16(1), 4-18.

Sileshi, G., et al. (2019). Agroforestry for ecosystem services and environmental benefits: An overview. Agroforestry Systems, 93(5), 1381-1388.

Falconer, J. (2019). Agroforestry extension: A way forward for widespread adoption. Agroforestry Systems, 93(5), 1541-1554.

Franzel, S., et al. (2014). Scaling up the impacts of agroforestry: Lessons from three sites in Africa and Asia. Agroforestry Systems, 88(4), 641-651.

Garrity, D., et al. (2016). Agroforestry and landscape restoration: Reforestation and land-use change in a densely populated country. In: Agroforestry - The Future of Global Land Use. Springer, Cham, 277-294.

Jha, P., et al. (2017). Extension education in agroforestry: A review. Indian Journal of Extension Education, 53(3-4), 62-71.

Kiptot, E., et al. (2018). Role of extension agents in adoption of agroforestry technologies: Evidence from western Kenya. Journal of Agricultural Extension and Rural Development, 10(1), 1-10.

Nair, P. K. R (1993). An Introduction to Agroforestry. Kluwer Academic Publisher, London.499p.

Nair, P. K. R., et al. (2020). Agroforestry as a sustainable land use option in the tropics: The Latin American experience. Agroforestry Systems, 94(6), 2231-2251.

Russo, L., et al. (2021). Agroforestry as a climate change mitigation option in the tropics: An integrated modeling framework for policy support. Environmental Modelling& Software, 140, 105057.

Sinclair, F., et al. (2019). Agroforestry education and training: Present and future. Agroforestry Systems, 93(5), 1555-1571.

Sileshi, G., et al. (2020). Agroforestry as a strategy for climate change adaptation and mitigation in Africa. Forests, Trees and Livelihoods, 29(1), 1-23.

The Khejari tree: An overview of its ecological significance, uses and potential for agroforestry systems

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Abstract

The Khejari tree (*Prosopis cineraria*), often referred to as the "tree of life" in arid regions, is an essential species in the desert ecosystems of the Indian subcontinent. This review article delves into the tree's ecological importance, varied applications, and cultivation methods. Furthermore, it examines the potential of Khejari in agroforestry systems, emphasizing its advantages for sustainable agriculture and environmental conservation.

Introduction

Prosopis cineraria, commonly known as the Khejari tree, is a leguminous tree native to arid and semi-arid regions of India, Pakistan, and parts of the Middle East. It is renowned for its drought tolerance, nitrogen-fixing ability, and multifaceted uses. This tree holds cultural, ecological, and economic importance in the regions where it thrives.

Ecological significance

Soil improvement and erosion control

Khejari trees play a crucial role in improving soil fertility through nitrogen fixation. The tree's root system harbors nitrogen-fixing bacteria (Rhizobium), which convert atmospheric nitrogen into a form usable by plants. This enriches the soil, promoting the growth of other vegetation and enhancing overall ecosystem productivity.

The extensive root system of the Khejari tree also helps in stabilizing soil, preventing erosion, and maintaining soil structure. This is particularly important in arid regions prone to desertification.

Biodiversity and habitat

Khejari trees provide habitat and food for various wildlife species. The tree's flowers attract pollinators such as bees, while its pods serve as a food source for herbivores. Birds use the tree for nesting, and the foliage offers shade and shelter to many animals.

Uses of Khejari tree

Besides the ecological value of *P. cineraria* tree, there are significant utilizations centered on its use for human food, animal feeds, medical purposes and many other applications. The multipurpose and added value usages of ***P. cineraria*** tree; barks, pods, and leaves; will be discussed with regards to its health benefits and nutraceutical effects as follow:

Fodder and food

The leaves and pods of the Khejari tree are highly nutritious and are commonly used as fodder for livestock. The pods, known as "Sangri," are rich in protein and are a staple food in some rural communities. Sangri is often dried and cooked with spices to make a traditional dish called "Panchkuta."

Timber and fuelwood

Khejari wood is durable and resistant to termites, making it valuable for construction and furniture making. It is also used as fuelwood in rural areas, providing an essential energy source for cooking and heating.

Medicinal uses

Various parts of the Khejari tree have medicinal properties. The bark, leaves, and pods are used in traditional medicine to treat ailments such as respiratory disorders, skin diseases, and digestive issues. The tree's bark is known for its anti-inflammatory and antimicrobial properties.

Environmental benefits

The Khejari tree helps in carbon sequestration, contributing to climate change mitigation. It also improves air quality by absorbing pollutants and providing oxygen.

Cultivation practices

Planting and propagation

Khejari trees can be propagated through seeds or cuttings. Seeds should be soaked in water for 24 hours before planting to enhance germination. The best time for planting is during the monsoon season when soil moisture is adequate.

Soil and water requirements

In its natural habitat, the Khejari tree thrives in regions with annual rainfall ranging from 100 to 500 mm, with optimal density found in areas receiving 350-400 mm of rainfall. These trees adapt well to various soil types, including sandy, loamy, and saline soils. They require minimal water once established, making them perfect for arid and semi-arid regions. However, irrigation is essential during the early stages of growth to ensure proper establishment.

Pruning and maintenance

Regular pruning helps in maintaining the tree's shape and encourages healthy growth. It also prevents the spread of pests and diseases. Mulching around the base of the tree can help retain soil moisture and suppress weed growth.

Potential for agroforestry systems

Khejari trees have significant potential for integration into agroforestry systems due to their multiple benefits:

Soil fertility enhancement

The nitrogen-fixing ability of Khejari trees improves soil fertility, benefiting associated crops. This can lead to increased agricultural productivity and reduced dependence on chemical fertilizers.

Shade and microclimate regulation

Khejari trees provide shade, reducing soil temperature and moisture loss. This creates a favorable microclimate for understory crops, enhancing their growth and yield.

Livelihood support

By providing fodder, fuelwood, and food, Khejari trees support the livelihoods of rural communities. The sale of Sangri pods and timber can generate additional income for farmers.

Biodiversity conservation

Integrating Khejari trees into agroforestry systems promotes biodiversity by providing habitat and food for various species. This enhances ecosystem resilience and sustainability.

Conclusion

The Khejari tree (*Prosopis cineraria*) is a keystone species in arid and semi-arid regions, offering numerous ecological, economic, and social benefits. Its ability to improve soil fertility, provide fodder and food, and support livelihoods makes it an invaluable resource for sustainable agriculture and environmental conservation. Integrating Khejari trees into agroforestry systems holds great promise for enhancing productivity, biodiversity, and resilience in these fragile ecosystems.

Future efforts are required to be focus on integrated management of ***P. cineraria*** in their natural ecosystem and implement environmental conservation strategies for achieving sustainable uses and maintain its benefits to livelihood and coming generation.

References

Bhansali, R. R. (1998). *Prosopis cineraria*: A tree of desert. Annals of Arid Zone, 37(4), 377-384.

Garg A, Mittal SK. Review on Prosopis cineraria: A potential herb of Thar desert. Drug Invention Today. 2013;5:60-65. DOI: 10.1016/j.dit.2013.03.002

Harsh, L. N., Tewari, J. C., & Singh, S. (1992). Khejri (*Prosopis cineraria*) in the Indian desert: Its role in agroforestry. International Tree Crops Journal, 7(4), 177-182.

Mann, H. S., & Shankarnarayan, K. A. (1980). The role of *Prosopis cineraria* in an agroforestry system. Indian Forester, 106(2), 112-116.

Pareek, O. P. (1999). *Prosopis cineraria*: A versatile tree species of arid and semi-arid regions. Indian Horticulture, 43(4), 21-23.

Rani B, Singh U, Sharma R, Gupta A, Dhawan N, Sharma A, Maheshwari R. *Prosopis cineraria* (L.) druce: A desert tree to brace livelihood in Rajasthan. Asian Journal Pharmaceutical Research & Health Care. 2013; 5(2):58-64

Enhancing climate resilience and mitigation in forestry and tree-based agroecosystemsthrough biochar applications

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Forests, spanning nearly 4 billion hectares or 30% of Earth's land, play a pivotal role inregulating the global carbon cycle. Distributed across various biomes, including equatorial, tropical, Mediterranean, warm temperate, temperate, and boreal regions, natural forests exhibit diverse characteristics such as evergreen broadleaf, evergreen needle leaf, deciduous broadleaf, deciduous needleleaf, or mixed types (Easterling et al. 2007; Nabuurs et al. 2007; De Fries et al. 1998). The FAO reported a total biomass-C pool of approximately 282 Pg, with global forests' carbon pool estimated at around 633 Pg in 2005 (Marklund & Schoene, 2006).

Undisturbed forests tend to accumulate carbon due to photosynthesis exceeding respiration, but disturbances like wildfires, droughts, diseases, and anthropogenic activities offset this balance. Land-use changes, particularly deforestation, led to a significant reduction in forest area, with a global deforestation rate of 12.9 million ha year^{-1} from 2000 to 2005 (Nabuurs et al. 2007). Forest degradation, partly reversible through forestry projects, showed potential improvement as intensively managed forest plantations, constituting about 4% of the global forest area, experienced annual growth (Easterling et al. 2007).

Efforts in forestry, landscape restoration, and natural forest expansion have mitigated the net loss of forest lands to 7.3 million ha year^{-1} (Nabuurs et al. 2007). A recent synthesis study comparing primary and secondary natural forests with afforestation and reforestation plantations revealed an 11% lower above-ground biomass in plantations.

In plantation ecosystems, fine root biomass, soil organic carbon (SOC) concentration, and soil microbial carbon concentration were 66%, 32%, and 29% lower compared to natural forests, as reported by Liao et al. (2010). Additionally, Liao and colleagues found a 22%, 20%, and 26% reduction in available nitrogen (N), phosphorus (P), and potassium (K), respectively, in plantation soils compared to natural forests.

The relationship between forest productivity and climatic changes is significant. With global temperatures averaging 0.46°C above the 1961–1990 average from 2001 to 2010, there is a projected increase in the magnitude, frequency, and duration of extreme climatic events due to atmospheric warming. Particularly, warming trends in Africa, parts of Asia, and the Arctic have been notable. The Saharo-Arabian region, east Africa, central Asia, Greenland, and Arctic Canada experienced temperatures

1.2–1.4°C above the long-term average during 2001–2010, marking a 0.7–0.9°C increase compared to any previous decade (WMO 2011).

While rising atmospheric carbon dioxide (CO_2) concentrations may initially have a 'fertilization effect' on forests, enhancing their production capacity, continued warming is anticipated to diminish or potentially override this effect. Coupled with air pollution and decreasing nutrient availability, the overall impact on forest productivity remains uncertain. Global warming is expected to heighten risks from ozone (O_3), as increased fossil fuel use promotes O_3-forming pollutants, leading to decreased carbon sequestration in biomass and soil (Beedlow et al. 2004). The interplay between a system's productivity and resilience underscores the close association between mitigation and adaptation capacities in forest ecosystems (Kandji et al. 2006).

Biochar, a by-product of C-negative pyrolysis technology in bio-energy production, is generated through oxygen-excluded thermal decomposition of organic materials. When applied to soil, biochar's high porosity and negative charge enhance water-holding capacity and nutrient retention, leading to increased water and nutrient availability for plant uptake. This application improves soil physical and chemical qualities, resulting in higher net primary productivity of the agro-ecosystem. Additionally, biochar's recalcitrant nature hinders microbial decomposition, enabling long-term carbon sequestration in soil. The characteristics of biochar, such as salt and ash content, carbon-nitrogen ratio, and cation exchange capacity, are influenced by feedstock type and pyrolysis temperature. The production process is cost-effective, making it accessible to low-income populations. In 2011, the International Biochar Initiative reported 154 biochar projects across 43 developing countries, involving various organic materials and production scales. These projects ranged from household to regional levels, utilizing technologies like batch retort kilns and continuous process kilns.

Despite the agronomic and environmental benefits of biochar, its production and use pose potential environmental and health risks due to the presence of toxic compounds such as heavy metals, dioxins, and polycyclic aromatic hydrocarbons (PAHs), likely originating from contaminated feedstocks or specific processing conditions (Verheijen et al., 2010). Temperature modification during pyrolysis can partially control PAH composition (Kloss et al., 2012), and careful control of feedstock and pyrolysis conditions may reduce PAH levels, as well as emissions of dioxins and particulate matter associated with biochar production (Verheijen et al., 2010).

Despite widespread use in agriculture, limited research has explored biochar's application in forestry and tree-based agro-ecosystems. This study aims to assess the potential of enhancing carbon sequestration in these systems through the application of stable carbon-based soil amendment. Additionally, the study investigates the anticipated improvement in soil quality and fertility, exploring the potential of biochar to enhance forest resilience or adaptation to climate change. Considering four major pathways for mitigating carbon emissions in forestry activities (increasing forested land area, raising carbon density in existing forests, sustainable use of forest products, and reducing emissions from deforestation and land degradation), this review addresses each pathway directly or indirectly. The objectives of this review include raising awareness of biochar applications, highlighting implementation challenges, and emphasizing the need for international regulations to facilitate widespread adoption of this practice.

Carbon cycle in relation to deforestation

Deforestation is identified as the second-largest anthropogenic contributor to atmospheric CO_2 levels, following fossil fuel combustion. Recent estimates attribute between 12% (van der Werf et al., 2009) and 20% (Gullison et al., 2007) of total emissions to cumulative deforestation and forest degradation. Conservative estimates suggest emissions of approximately 1.2 Pg C year^{-1} from 1997 to 2006 (van der Werf et al., 2009). Wildfires, a significant factor in altering forest characteristics, emit substantial CO2 while also generating ash and charcoal that modify forest lands. In particular, wildfires provide valuable insights into the impact of charcoal on forest ecosystems, as demonstrated in a greenhouse study in the northern boreal zone of Sweden. The study revealed increased shoot-to-root ratio in Silver birch (Betulapendula Roth) and Scots pine (Pinussylvestris L.) when exposed to wildfire-produced charcoal, attributed to enhanced nutrient uptake. This research contributes crucial information given the limited studies on biochar in forestry systems, enhancing our understanding of related processes. For instance, findings align with Wardle et al. (1998), DeLuca et al. (2006), and MacKenzie and DeLuca (2006), emphasizing the positive effects of charcoal on nutrient dynamics and nitrification rates in different forest ecosystems.

The persistence of ash, charcoal, or black carbon in ecosystems has been widely acknowledged (Lehmann et al. 2008; Abiven and Andreoli 2011; de Lafontaine and Asselin 2011). Nocentini et al. (2010) found that the decomposability of charcoal is influenced by particle size, with <0.5 mm charcoal from a moderate-intensity wildfire being 24% of the total mass and rich in N, potentially susceptible to microbial decomposition. Wood-derived charcoal was prevalent in >2 mm fractions, while smaller fractions contained pine needles and herbs. Extreme fires in mixed-species eucalypt forests and temperate rainforests in Victoria, Australia, converted tree biomass into ash, depositing 4.8 to 8.1 Mg C ha^{-1} on the forest floor, with subsequent redistribution. Wardle et al. (2008) reported increased forest humus loss when mixed with charcoal in a Swedish boreal forest study, suggesting that despite long-term sequestration of charcoal-C, it may be partially offset by stimulating plant litter-C loss. However, a 240-day study by Abiven and Andreoli (2011) found no impact of charcoal on decomposition rates in a mixed forest in Switzerland. The influence of charcoal on surrounding organic substances appears to depend on their nature, soil conditions, and temporal duration.

Deforestation heightens the impact of climate change on remaining forests, especially in tropical regions facing increased drought risks (Gullison et al.

2007). The Amazon Basin, at risk due to more frequent and severe droughts, could emit 15 to 26 Pg C into the atmosphere if droughts persist (Nepstad et al. 2008). Model projections suggest a more than 20% decrease in rainfall across some parts of the Amazon Basin by the end of the twenty-first century due to the accumulation of greenhouse gases (GHGs) and associated radiative forcing (IPCC 2008).

Afforestation of degraded lands and carbon cycle

Afforestation is crucial for addressing widespread land degradation, affecting approximately 24% of the world's terrestrial area and impacting 1.5 billion people (Bai et al., 2008). Degradation processes, such as reduced vegetation cover and soil organic carbon (SOC) depletion, lead to compromised soil structure and increased vulnerability to erosional processes (Lal, 2002). This results in heightened raindrop impact, reduced soil hydraulic conductivity, and loss of the fertile top layer (Stavi&Lal, 2011a). SOC lost through erosion can either be emitted as CO_2 or accumulate in depositional sites, contributing to soil fertility degradation (Stavi&Lal, 2011b; Gregorich et al., 1998). Afforestation efforts play a crucial role in mitigating these negative impacts, promoting sustainable land management and restoring soil productivity.

Afforestation projects are feasible on degraded lands across various terrestrial and climatic conditions globally. These projects, aimed at improving ecosystem services and biodiversity conservation, are already underway in many countries and involve millions of smallholder farmers engaged in tree planting and forest management. Chazdon (2008) emphasizes the need for adaptive management in creating resilient forests that can withstand climate change, habitat fragmentation, and other disturbances.

Biochar application has been identified as a promising method to restore degraded lands. Studies by Sohi et al. (2009) and Stavi (2012) demonstrate its capability. Utilizing biochar on degraded lands for afforestation is proposed, as it enhances water and nutrient retention in the soil, promoting favorable conditions for tree growth. The alkaline nature of biochar can also positively impact soil pH, particularly in highly weathered soils, potentially neutralizing acidity and increasing tree productivity, thus enhancing land restoration capacity.

The application of biochar can be achieved by spreading it on the land surface and either incorporating it into the soil or retaining it on the ground. While surface retention minimizes soil erosion risk, it may limit soil nutrient improvement and is susceptible to redistribution. Incorporating biochar into the soil is preferred, though limited machinery is currently developed for this purpose. Modified conventional spreaders and hand-operated rotavatormachines can be utilized for small-scale application, while tractor-drawn ploughs, disk ploughs, or rotavators are suitable for extensive land areas, with application depth tailored to terrestrial conditions and tree species.

For optimal results, biochar application should precede tree planting, covering the entire project area for new afforestation projects. In established projects, biochar should be applied in inter-rows. When determining application rates, terrain conditions, such as steep slopes or exposed bedrocks, must be considered, as they impact accessible land area.

Pyrolysis feedstocks for biochar production, whether for co-production with bio-energy or standalone biochar production, can include diverse materials like forestry residues, domestic wastes, sewage sludge, and low-input, non-food competing crops. However, residues crucial for maintaining soil organic carbon (SOC) stock, supporting the soil food web, and preventing erosion, like wheat straw or corn stalk, should not be considered as relevant feedstocks.

Maintenance actions for established afforestation systems, such as trimming and thinning, should ideally leave some prunings on the surface to prevent erosion and replenish SOC stock. Waste materials, when cleared, could be repurposed as feedstock for bio-energy or biochar production.

Biochar management presents environmental, social, and economic benefits. It can lead to new businesses, job opportunities, and increased income in rural regions. However, economic calculations and site-specific life-cycle assessments are crucial to ensure net economic profit and carbon sequestration, considering costs and emissions related to waste collection, transportation, and processing. Inclusion of biochar management under international carbon finance mechanisms may help offset costs.

Niles et al. (2002) conducted a comprehensive 10-year study (2003-2012) on reforestation projects in 48 sub-tropical and tropical developing countries. They determined reforestation rates of ~1.7, 1.1, and 0.7 million ha year−1 in Latin America, Asia, and Africa, potentially totaling~3.5 million ha year−1. The resulting vegetative-C accumulation capacity, excluding soil organic carbon (SOC), was ~178, 96, and 42 Tg, totaling~316 Tg over the study period. Biochar application to soil could enhance carbon stocks in these systems. In developed countries, integrating biochar into the established bio-energy industry is feasible, while in developing countries, low-tech biochar production may be more practical.

Despite the potential benefits, rural populations in developing countries relying on traditional energy sources may lack motivation to use biochar. To encourage change, international policies should consider biochar application in reforestation projects for funding under carbon finance mechanisms. Extension activities should educate locals on the long-term advantages, promoting widespread implementation.

Life cycle assessments of residue conversion into bio-energy or biochar should be site-specific to verify environmental sustainability, considering emissions from feedstock collection, transportation, processing, and spreading. The overall environmental footprint should be lower than alternative practices.

Reforestation and carbon

In managed reforestation lands, retaining some residues on the forest floor is preferable to maintain SOC stocks and control erosion. Gregg and Smith (2010) suggested a minimum retention of 20 Mg ha−1, allowing excess residues beyond this threshold to be used for bio-energy or biochar production. The 'whole tree method' in some regions may pose environmental risks, and converting some residues to biochar could improve soil quality.

Despite the potential benefits of biochar application in forest lands, it has received limited attention. Studies in Indonesia and Japan have shown positive effects on tree growth, mycorrhizal fungus yields, and seedling survival. Wood ash derived from biomass burning in power plants has also been studied for soil amendment in forestry systems. Further research and promotion of biochar application in forest lands are warranted.

Despite limited documentation on biochar application in forest lands, extensive research has been conducted on the use of wood ash derived from biomass combustion in power plants. Wood ash serves as a valuable soil amendment in forestry systems, mitigating soil acidification and compensating for nutrient depletion resulting from intense logging practices like whole-tree harvesting (Saarsalmi et al. 2004). In northwestern Spain, Santalla et al. (2011) investigated the impact of mixed wood ash, applied at a rate of 7.5 Mg ha^{-1}, on soil nutrient status in an intensive forest system planted with Monterey pine (Pinusradiata D. Don). In this subhumid Mediterranean region, characterized by an organic-rich, highly acidic A horizon with low nutrient availability, the application of ash restored soil reserves of Ca, Mg, and K in the organic layer. However, wood ash also decreased P availability due to its charcoal content, temporarily reducing mineral P solubility. Despite this, the combined application of wood ash and mineral P fertilizer improved P concentration in needles, litterfall, and soil. Additionally, wood ash decreased soil N mineralization rate and mineral N concentrations, attributed to increased microbial activity and the high C : N ratio in the ash. This impact may negatively affect tree growth by inducing N deficiency in plants. Studies have shown that wood ash alone may have negligible economic benefits on poor mineral soils, while its combination with mineral N can enhance tree growth in N-rich mineral soils (Solla-Gullón et al. 2008).

The impact of wood ash combined with mineral N on plant nutrient availability and tree growth has been intensively studied. For example, in southern Finland, the application of 3 Mg ha−1 of wood burnt-bark ash combined with 150 kg N ha^{-1} in a 45-year-old Norway spruce stand increased pH, base saturation, and concentrations of nutrients in the soil's organic layer (Helmisaari et al. 2009). However, over a 10-year period, this treatment reduced fine root biomass by ∼30%, while K concentrations in needles increased. Overall tree growth remained similar to non-amended soil. In another study in 31- and 75-year-old coniferous stands in southern Finland, wood ash alone had no impact on needle nutrient concentrations, but combined with N fertilizer increased nutrient concentrations. No impact on tree growth was observed under ash alone, with a slight increase when combined with N, diminishing after the first 5 years (Saarsalmi et al. 2004, 2006).

Wood ash chemistry is influenced by factors such as tree species, burning process, and application site conditions. Hardwood species produce ash with higher macronutrient levels than conifers, and furnace temperature during burning (500˚C to 900˚C) is crucial for nutrient retention, particularly K. The mode of ash application and particle size also affect nutrient availability, with soil incorporation enhancing solubility and promoting tree growth.

Concerns about wood ash increasing heavy metal concentrations in soil, such as cadmium (Cd), have been raised. Fly ash, a lighter component accumulating in the flue system, can contain high levels of Cd, Cu, Cr, Pb, and As. However, mixed wood ash, comprising fine fly ash and bottom wood ash, is less reactive and contains lower trace element amounts, reducing the risk of heavy metal contamination (Pitman 2006; Solla-Gullón et al. 2008).

The impact of higher wood ash application rates on forestry system productivity and potential toxic effects is debatable (Saarsalmi et al. 2006; Pitman 2006). Biochars, derived from different feedstocks and pyrolysis conditions, may contain heavy metals and other contaminants, necessitating pre-pyrolysis testing of feedstocks and post-production examination of biochars to avoid ecotoxic effects (Ernsting 2011). Further research is required to understand the mechanisms leading to the formation and retention of contaminants in biochar (Verheijen et al. 2010).

The economic viability of converting forest residues into bio-energy or biochar depends on various factors, including terrain, climate, fuel prices, technology, transportation, and proximity to power plants. To minimize costs associated with transportation, on-site conversion is recommended (Leinonen 2004; Matovic 2011). Economic calculations for bio-energy or biochar production should be site-specific, encompassing all feedstock processing costs.

For reforestation lands, biochar application before tree planting can enhance capacity and potential production. Similar to afforestation, consideration of physical terrain restrictions is crucial in calculating biochar application capacity.

The impact of wood ash on soil and stand productivity varies with site, time, and ash features. Most studies focus on humid and temperate regions with acidic soils and coniferous stands, leaving a significant gap in research for Mediterranean or drier regions, alkaline soils, and broadleaf stands.

Multipurpose agroforestry

Agroforestry systems, covering 46% of global agricultural land area, are prevalent in Southeast Asia, Central America, and South America, impacting over 1 billion ha of land and 558 million people (Zomer et al. 2009). These multipurpose systems provide various products over time intervals, optimizing space and nutrient extraction from different soil layers efficiently. Agroforestry systems can sequester carbon (C), enhance resilience to climate change, and provide additional ecosystem services, such as improved water use efficiency, shading, nutrient turnover, and micro-habitat conditions for crops. However, the efficiency of C sequestration depends on factors like perennial crops and management practices. Agroforestry systems may also influence nitrous oxide emissions and exhibit resilience to pest infestation through increased plant biodiversity. More research is needed to understand the full potential and limitations of agroforestry systems in different regions and under various management practices.

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In agroforestry systems, the use of biochar from tree prunings serves as an effective means of erosion control, maintaining soil quality on-site and safeguarding water sources off-site. However, the collection, transportation, and processing of prunings may lead to greenhouse gas emissions, potentially offsetting carbon sequestration gains. Despite this, the transition from burning prunings to biochar production is considered environmentally sustainable. The integration of biochar into agroforestry systems is anticipated to decrease nutrient leaching, minimizing groundwater contamination, and enhance soil stability, reducing water overland flow and erosional processes. These positive effects extend to mitigating eutrophication and siltation in above-ground water sources. Additionally, biochar application is linked to reduced emissions of N_2O and CH_4, contributing to improved fertilizer efficiency and decreased greenhouse gas emissions.

Monoculture plantations and tree orchards

In agroforestry systems, the assumed 50% coverage of ground surface by trees' inter-row spaces suggests potential cultivability, mitigating the limitation observed elsewhere. Existing agroforestry systems alone could sequester a minimum of 2 Pg of biochar-C. Additional sequestration is feasible in global fruit tree orchards and bio-energy plantations. Implementing biochar management practices has the potential to enhance soil quality, bolstering the resilience and adaptive capacity of forestry and tree-based agro-ecosystems to changing climatic conditions. However, site-dependent impacts are anticipated, necessitating region-specific biochar types and application rates. Combining biochar with mineral N or P, or livestock manure, may enhance nutrient availability and productivity. Notably, existing studies predominantly focus on wildfire charcoal or wood ash from biomass burning, underscoring the need for extensive research to comprehend biochar's effects on forestry and tree-based agro-ecosystems. Addressing potential ecotoxic effects is crucial to mitigate adverse impacts on human health and the environment. International regulations should recognize biochar as an eligible strategy for funding under the C finance mechanism, facilitating its global expansion.

Expanding on these benefits, incorporating biochar into mono-culture fruit tree orchards and bio-energy tree plantations is a relevant management practice. Similar to other tree-based agro-ecosystems, applying biochar across the entire area before planting maximizes carbon sequestration capacity. In established orchards or plantations, biochar application in inter-row spaces is suggested. Various tree prunings, such as those from vines, olive, apple, pear, peach, citrus, almond, hazelnut, coconut, cocoa, and date palm trees, can serve as ample feedstocks for biochar production. Despite the associated greenhouse gas emissions during collection and processing, the overall environmental benefits of converting prunings to biochar are highlighted, especially in regions where burning is a common disposal practice. Highly productive bio-energy crops, such as eucalyptus, can efficiently provide sufficient biochar for on-site application during a single harvest, offering a sustainable approach to soil improvement. Historical evidence from Japan supports the positive impact of biochar on fruit tree growth, demonstrating enhanced root length, shoot productivity, net primary productivity (NPP), and mycorrhizal development. The combination of agroforestry systems and biochar application emerges as a powerful strategy for climate change mitigation and adaptation, presenting significant agricultural and environmental advantages. In forestry and tree-based agro-ecosystems, the use of biochar is expected to enhance productivity and reduce environmental impact, similar to agroforestry systems. This includes a decrease in fertilizer rates, leading to a reduction in greenhouse gas emissions and pollution in water sources. The global focus on mitigating carbon emissions has led to international projects, such as tropical deforestation prevention and reforestation efforts, with the potential for significant funding through carbon credit trading mechanisms. However, challenges include the need for technical and institutional capacities, measurement systems, and commitment from developed countries.

The Clean Development Mechanism (CDM) and Reducing Emissions from Deforestation and Degradation (REDD) programs have been applied to developing countries but may have strict rules and limitations for small-scale farmers. Successful implementation requires addressing social, cultural, and political contexts, local stakeholder participation, and fair CDM payments. Additionally, the biochar management practice is proposed as a strategy for carbon sequestration, but its application is not currently eligible for CDM funding.

Biochar production costs and C offset values vary, with considerations for feedstock types. Despite its potential in forestry and tree-based systems, biochar projects require regulated financing to be viable. A life cycle assessment indicates the profitability of biochar systems depends on offset prices and feedstock costs.

Considering the unresolved regulatory framework for biochar projects, authorities could provide payments to landowners for ecosystem service improvements, including carbon sequestration, soil erosion control, water quality preservation, and biodiversity increase. Extensive research is needed to assess the potential of biochar application in forestry and tree-based agro-ecosystems for climate change mitigation and adaptation.

In conclusion, natural carbon sequestration in forestry and tree-based systems can be enhanced through biochar application, offering potential benefits in offsetting atmospheric CO_2 concentrations. However, the regulatory framework, financing mechanisms, and comprehensive research must be addressed to ensure the success of such practices.

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References

Abiven S, Andreoli R. 2011. Charcoal does not change the decomposition rate of mixed litters in a mineral cambisol: a controlled conditions study. BiolFertil Soils. 47:111–114.

Bai ZG, Dent DL, Olsson L, Schaepman ME. 2008. Proxy global assessment of land degradation. Soil Use Manage. 24:223–234.

Beedlow PA, Tingey DT, Phillips DL, Hogsett WE, Olszyk DM. 2004.Rising atmospheric CO2 and carbon sequestration in forests. Front Ecol Environ. 2:315–322.

Chazdon RL. 2008. Beyond deforestation: restoring forests and ecosystem services on degraded lands. Science. 320:1458–1460.

De Fries RS, Hansen M, Townshend JRG, Sohlberg R. 1998. Global land cover classifications at 8 km spatial resolution: the use of training data derived from Landsat imagery in decision tree classifiers. Int J Remote Sens. 19:3141–3168.

de Lafontaine G, Asselin H. 2011. Soil charcoal stability over the Holocene across boreal northeastern North America.Quat Res. 76:196–200.

DeLuca TH, MacKenzie MD, Gundale MJ, Holben WE. 2006. Wildfire-produced charcoal directly influences nitrogen cycling in Ponderosa pine forests. Soil SciSoc Am J. 70:448–453.

Easterling WE, Aggarwal PK, Batima P, Brander KM, Erda L, Howden SM, Kirilenko A, Morton J, Soussana JF,

Schmidhuber J, et al. 2007. Food, fibre and forest products. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ,

Ernsting A. 2011. Biochar – a climate smart solution? Climate Change and Agriculture, Report No. 1. e.V. Aachen: Bischöfliches Hilfswerk MISEREOR.

Gregg JS, Smith SJ. 2010. Global and regional potential for bioenergy from agricultural and forestry residue biomass. Mitig Adapt Strateg Glob Change. 15:241–262.

Gregorich EG, Greer KJ, Anderson DW, Liang BC. 1998. Carbon distribution and loses: erosion and deposition effects. Soil Tillage Res. 47:291–302.

Gullison RE, Frumhoff PC, Canadell JG, Field CB, Nepstad DC, Hayhoe K, Avissar R, Curran LM, Friedlingstein P, Jones CD, et al. 2007. Tropical forests and climate policy. Science.316:985–986.

Helmisaari HS, Anna Saarsalmi A, Kukkola M. 2009. Effects of wood ash and nitrogen fertilization on fine root biomass and soil and foliage nutrients in a Norway spruce stand in Finland. Plant Soil. 314:121–132.

IPCC. 2008. Technical paper on climate change and water. Geneva:

Intergovernmental Panel on Climate Change.

Kandji ST, VerchotLV,Mackensen J, Boye A, van Noordwijk M, Tomich TP, Ong C, Albrecht A, Palm C. 2006. Opportunities for linking climate change adaptation and mitigation through agroforestry systems. In: Garrity D, Okono A,

Kloss S, Zehetner F, Dellantonio A, Hamid R, Ottner F,Liedtke V, Schwanninger M, Gerzabek MH, Soja G. 2012. Characterization of slow pyrolysis biochars: effects offeedstocks and pyrolysis temperature on biochar properties.

J Environ Qual. 41:990–1000. Kyoto protocol to the United Nations framework convention toclimate change. 1998. United Nations.

Lehmann J, Skjemstad J, Sohi S, Carter J, Barson M, Falloon P,Coleman K, Woodbury P, Krull E. 2008. Australian climatecarboncycle feedback reduced by soil black carbon. NatGeosci. 1:832–835. doi:10.1038/ngeo358.

Leinonen A. 2004. *Harvesting technology of forest residues forfuel in the USA and Finland*.VTT Research Notes 2229. Jyväskylä: Julkaisija-Utagivare Publisher.

Liao C, Luo L, Fang C, Li B. 2010. Ecosystem carbon stockinfluenced by plantation practice: implications for planting forests as a measure of climate change mitigation. PloS One.5:e10867.

MacKenzie MD, DeLuca TH. 2006. Charcoal and shrubs modifysoil processes in ponderosa pine forests of western Montana.Plant Soil. 287:257–266.

Marklund KG, Schoene D. 2006. *Global forest resources assessment2005*. Rome: Global FAO Forestry Department.

Matovic D. 2011. Biochar as a viable carbon sequestration option:global and Canadian perspective. Energy. 36:2011–2016.

Nabuurs GJ, Masera O, Andrasko K, Benitez-Ponce P, BoerR, Dutschke M, Elsiddig E, Ford-Robertson J, Frumhoff P,

Karjalainen T, et al. 2007. Forestry. In: Metz B, DavidsonOR, Bosch PR, Dave R, Meyer LA, editors. Climate change 2007: mitigation. Contribution of Working Group III to theFourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press; p 541–584.

Nepstad DC, Stickler CM, Soares-Filho B, Merry F. 2008.Interactions among Amazon land use, forests and climate: prospects for a near-term forest tipping point. Philos TransR Soc B. 363:1737–1746. doi:10.1098/rstb.2007.0036.

Niles JO, Brown S, Pretty J, Ball AS, Fay J. 2002. Potential carbon mitigation and income in developing countries from changes in use and management of agricultural and forestlands. Philos Trans R Soc A. 360:1621–1639. doi:10.1098/ rsta.2002.1023.

Nocentini C, Certini G, Knicker H, Francioso O, Rumpel C. 2010.Nature and reactivity of charcoal produced and added to soilduring wildfire are particle-size dependent. Org Geochem.41:682–689.

Pitman RM. 2006. Wood ash use in forestry – a review of theenvironmental impacts. Forestry. 79:563–588.

Saarsalmi A, Kukkola M, Moilanen M, Arola M. 2006. Longtermeffects of ash and N fertilization on stand growth, tree nutrient status and soil chemistry in a Scots pinestand. Forest Ecol Manage. 235:116–128.

Saarsalmi A, Mälkönen E, Kukkola M. 2004. Effect of woodash fertilization on soil chemical properties and stand nutrient status and growth of some coniferous stands inFinland. Scand J Forest Res. 19:217–233.

Santalla M, Omil B, Rodríguez-Solleiro R, Merino A. 2011.Effectiveness of wood ash containing charcoal as a fertilizer for a forest plantation in a temparate region. Plant Soil.346:63–78.

Sohi S, Lopez-Capel E, Krull E, Bol R. 2009.*Biochar, climatechange and soil: a review to guide future research*. CSIRO Land and Water Science Report 05/09. Melbourne: CSIRO.

Solla-Gullón F, Santalla M, Pérez-Cruzado C, Merino A,Rodríguez-Soalleiro R. 2008. Response of *Pinusradiata* seedlings to application of mixed wood-bark ash at plantingin a temperate region: nutrition and growth. Forest Ecol Manage. 255:3873–3884.

Stavi I. 2012. The potential use of biochar in reclaimingdegraded rangelands. J Environ Plann Man. 55:657–665.

Stavi I, Lal R. 2011a. Loss of soil resources from watererodedversus uneroded cropland sites under simulated rainfall. Soil Use Manage. 27:69–76.

Stavi I, Lal R. 2011b.Variability of soil physical qualityin uneroded, eroded, and depositional cropland sites. Geomorphology. 125:85–91.

van der Werf GR, Morton DC, De Fries RS, Olivier JGJ,Kasibhatla PS, Jackson RB, Collatz GJ, Randerson JT. 2009. CO2 emissions from forest loss. Nat Geosci. 2:737–738.

Verheijen F, Jeffery S, Bastos AC, van der Velde M, DiafasI. 2010. *Biochar application to soils – a critical scientific review of effects on soil properties, processes and functions*.Ispra: Joint Research Centre, the European Commission.

Wardle DA, Nilsson MC, Zackrisson O. 2008. Fire-derivedcharcoal causes loss of forest humus. Science.320:629. doi:10.1126/science.1154960.

Wardle DA, Zackrisson O, NilssonMC. 1998. The charcoal effectin Boreal forests: mechanisms and ecological consequences.Oecologia. 115:419–426.

WMO. 2011. *Weather extremes in a changing climate: hindsighton foresight*. Geneva: World Meteorological Organization.

Zomer RJ, Trabucco A, Coe R, Place F. 2009. *Trees on farm:analysis of global extent and geographical patterns of agroforestry*. ICRAF

Working Paper No. 89. Nairobi: WorldAgroforestry Centre.

Assessment of propagation techniques for *Albizzia lebbeck*

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Abstract

Albizzia lebbeck is a medium to fast-growing, drought-tolerant nitrogen-fixing tree, widely introduced and now found throughout the tropics It can tolerate saline, alkaline, and marginal soils and is used for timber, fuel, and fodder. *Albizia*, a subfamily of the Fabaceae family, is a versatile tree with over 160 species found in Asia, Africa, Madagascar, America, and Australia. It is also used in traditional medicine, timber, and fodder production. *Albizias* are small trees or shrubs with rapid growth and short lives, with colorful stamen-covered flowers and a sizable strap-shaped fruit.

Key words:- *Albizzia lebbeck*, Agroforestry, Fast- growing, Phenology

Introduction

Agroforestry is a sustainable land and crop management system in India that aims to increase yields by growing arable crops, animals, and woody forestry crops on the same land unit. It includes conventional and contemporary land-use arrangements, creating jobs and value addition for rural and urban residents. Agroforestry systems have a great potential for sequestering carbon, they may act as a carbon sink and mitigate the negative effects of climate change on the planet., agroforestry in India has the potential to sequester 0.25 to 19.14 Mg C ha–1 yr^{-1}.

Ecology

Albizzia lebbeck is a dominating species in semi-evergreen vine forests (monsoon forest) that experience verydrywintersand meanannualprecipitationof1300–1500mm.Additionally, it can be discovered in semi-deciduous microphyll vine thickets on quartz sandstone mountain screes.Itisresilienttolong, hot, dryspellsand harshwinters.The plant thrives in soils that cover basalt as well as among sandstone rocks and basalt outcrops on breakaway slopes. It is also found on the banks of riverine areas, low lateritic ledges above the coast, and stabilised dunes. After the first year, it is resistant to drought and moderate frost.

Environmental requirements

India is home to a variety of climates, including hot and cold regions with temperatures up to 49°C and frost areas with a minimum temperature of -5°C.*Albizzia lebbeck*thrives in a range of climatic zones from sea level to 1500 m, with annual rainfall ranging from 600 mm to 2500 mm. However, it may also thrive in regions with low and erratic rainfall, as little as 300 mm per year.

Soil type

This plant thrives on fertile, well-drained loamy soils but struggles with heavy clays. It can tolerate acidity, alkalinity, heavy, eroded, and waterlogged soils like shallow sandy, laterite, and loam laterite.

Botanical features

General

*Albizzia lebbeck*is a deciduous tree with a grey fissured corky bark and reddish inner bark, reaching 15-20m tall and 1m in stem diameter. It grows in open spaces with multiple stems.

Foliage & pods

The compound leaves are bipinnate, glabrous, and have 2-4 pairs of obliquely oblong leaflets. They are briefly stalked, initially bright green, and ripen to duller glaucous green. The dry season only lasts 4-6 weeks.The mature seeds are pale straw to light brown, 8-10 x 6-7 mm, orbicular or elliptic, and 6-12 in per pod, with a flat, transverse arrangement.

Inflorescences, flowers and fruits

The plant has fragrant, pedunculate flower heads in an inflorescence, with a fluffy, yellow-green inflorescence. The mature pods are narrow-oblong, papery-leathery, and indehiscent, with pale straw to light brown color. Seeds are brown, flat, orbicular, or elliptic, and can travel great distances through wind.

Phenology

In India, flowering occurs mainly from March to May, and fruits grow to their full size from August to October. Plants grow from 0.5-2.0 m in height and 1.0-2.5 cm in stem diameter in 2-5 years, reaching 5 m/year under suitable conditions, and 2-2.2 m/year in dry tropics.During the wet season, trees continue to grow, flower, and germinate seeds, with mature pods remaining on the tree for three to four months.

Seed collection

Harvest ripe, healthy, and plentiful seed from January to March. Remove pods from trees using a long stick, and extract seeds by

Photo 1: Leaves, inflorescence, pods and seeds of Albizia lebbeck

lightly beating them after sun-drying. Seed yield is half of 1 kilogramme.

Harvest

Pluck pods after last green areas disappear and light yellow, as ripe pods can be infested quickly. Early collection after ripening in shade minimizes harm. Brown, flat seeds per kg.

Processing and handling

Pods, often infested with insects, should be stored briefly and kept open during transport. They are dried in the sun, threshed, and cleaned using seed cleaning equipment. The process ensures ventilation and prevents insects from growing during storage.

Storage and viability

Seeds can be stored at room temperature with minimal moisture content for up to a year, and can be stored in sacks or polythene bags for 4 to 5 years.Studies conducted in the U.P. reveal 24.6 39.2% germination after 11 and a half years and 32.6% germination after 2 and a half years.

Dormancy and pretreatment

Albizia lebbeck seeds, due to their tough coat, require pretreatment for germination. Various treatments, including dry heating, chemical scarification, mechanical scarification, warm water, and tap water, were investigated. Chemical scarification was the most effective, with 99% germination. High germination rates were also achieved by soaking seeds in heated water. Other common pre-treatments for leguminous seeds include soaking in concentrated sulfuric acid for five minutes and 24 hours, as well as immersion in boiling water. Seeds are submerged in boiling water for 24 hours, germination can be increased by soaking in hot or cold water, and pods are soaked for 12 hours before planting.

Nursery techniques

Seedlings can be raised in containers or nursery beds, with sunken beds used. Manure is added, soil pathogens tested, and fertiliser applied. Rhizobium and Azatobactor seed inoculation improves nodular mass, increasing dry matter production. Lime pelleting enhances this situation.Before sowing in the mother bed, immerse the seeds in cold water for two hours. After germination good seedlings should be transplanted. In 30 x 45 cmbags it attains 8 feet in six months.Seeds are sown in a mother bed, germinate from the third day, and after being pricked in polythene bags, 6 months old seedlings perform well in the field.

Direct sowing

It occurs just before or at the beginning ofthe monsoon.You can seed in a properlyprepared patch, mound, pit, or line. The most common method, line sowing on completely loosening soil, can produce about 70% success if continuous weeding is started soon away.

Entire transplanting

Seedlings develop quickly and reach 30 cm height for field planting in July. Survival rates range from 70-80, with better results in desert regions planting one-year-olds in the first half.

Stump planting

Seedlings are transplanted from nursery beds at 8 cm tall, and stumps are created when plants are 15 months old and the second rainy season begins. Planting between mid-July and mid-August is best, with a 100% success rate. Plants reach 60-90 cm tall after first rains.

Vegetative techniques

Vegetative propagation techniques are crucial for mass multiplication of multipurpose trees in agroforestry systems. A study developed a method for organogenesis-based in vitro regeneration of *Albizialebbeck*, using exogenous hormones from mature trees and juvenile seedlings. Explants from young seedlings showed more callusing.The most effective dose of benzyl aminopurine (3 g/l) was found to produce callusing in epicotyl and hypocotyl explants in 1/2 Murashige and Skoog media. A BA concentration of 3 g/l was beneficial for shoot proliferation.

The study found that a medium with 6 g/l IBA alone had the best rooting success rates, while sand or vermiculite with yoshida solution was the best hardening medium. Tissue culture-raised plants had higher height, collar diameter, biomass, and root shoot ratio.

Silviculture characteristics

*Albizia lebbeck*is a fast-growing, semi-deciduous, light and waterlogging tolerant tree suitable for tropics and subtropics, with moderate cold sensitivity and can be pruned or pollarded for a bushy crown.*Albizia lebbeck* has good pollarding and coppicing ability.

References

Balkrishna, A., Sakshi, Chauhan, M., Dabas, A., & Arya, V. (2022). A Comprehensive Insight into the Phytochemical, Pharmacological Potential, and Traditional Medicinal Uses of *Albizia lebbeck* (L.) Benth. *Evidence-Based Complementary and Alternative Medicine*, *2022*(1), 5359669.

Wikipedia (2016, August4). albizia. Encyclopedia Britannica. https://www.britannica Britannica, *T. Editors of Encyclopa*.com/plant/albizia

Review on *Albizia lebbeck* (L.) Benth: A Plant Possessing Diverse Pharmacological Activities K. Shirisha et al., *Research Journal of Pharmacognosy and Phytochemistry*, 2013

Gomo, M. S. M., Saint Goma, A. M. M., Ndzai, F., Foly Mpela, G., Kimposso, E. K. O., Douh, C., & N'zala, F. K. E. D. *Journal of Chemical, Biological and Physical Sciences.*

M.Faisal, P. P. Singh, and R. Irchhaiya,"Review on *Albizia lebbeck* a pot entherbal drug," *International Journal of Pharmaceutics*, vol. 3, no.5, pp. 63–68,2012.

S.S. Mishra V.K. Gothecha and Sharma, A., (2010) *ALBIZIA LEBBECK*: A SHORT REVIEW, *Journal of Herbal Medicine and Toxicology* 4 (2) 9-15 (2010)

From plant cells to pharmaceuticals: Harnessing the potential of cell suspension culture

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Medicinal plants have been a cornerstone of traditional medicine systems for centuries around the globe. They contain bioactive compounds that have therapeutic properties, making them an important asset to both natural health practices and contemporary medicine. These compounds are derived from various parts of plants such as leaves, roots, bark, fruits, and seeds, and exhibit a wide range of biological activities, including antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and anticancer effects. These bioactive compounds are called secondary metabolites, as they are not directly involved in the growth and development of the plants but perform their part in defense and adaptation to external stimuli. They have a huge market from cosmetics to nutraceuticals, every aspect of the health and beauty industry has garnered significant attention to these plants. These plant-based compounds serve as templates for synthetic drugs, bridging traditional and contemporary medical practices. However, there are many difficulties involved in the extraction of these bioactive compounds. Overexploitation or unsustainable harvesting poses a threat to the existence of these medicinal plants leading to the decline in their population and extinction. Their growth and distribution are also affected by climate change, like altered precipitation patterns, and extreme temperature conditions. Another major problem involved is the concentration of bioactive compounds can vary significantly depending on the growing conditions of the plant, harvest time, and part of the plant used. This variability complicates their standardization and quality control. These problems create a hurdle in the harvesting of these valuable compounds for their sustainable utilization.

In the quest for sustainable and efficient methods to harvest valuable biochemical compounds from plants, cell suspension culture has emerged as a groundbreaking technique. By utilizing plant cells in a controlled environment, this technique provides a robust and sustainable supply of bioactive substances. While conventional techniques for extracting plant materials from whole plants encounter obstacles such as resource scarcity and environmental effects, plant suspension cultures offer a viable substitute.

Cell Suspension culture (CSC) is a method of growing plant cells in a liquid nutrient media under a controlled environment. It is an efficient alternative method of obtaining bioactive compounds from plant cells in a large quantity. It involves several steps from initiation to maintenance and large-scale production of cells. They all are explained briefly here-

Initiation of cell suspension culture

Explant Selection- The crucial step is the selection of explants. The explant is an initial plant material with high regenerative capacities and is capable of developing different cells, tissues, and organs of the plant. Explants can be taken from stems, nodes, flowers, buds, seeds, roots, leaves, and embryos.

Sterilization- Since the plant part is taken from the external environment and there must be external contaminants like dust, dirt, and microbes stick to the plant part.To control microbial contamination, sterilizing agents are used. Some common sterilizing agents are ethanol, bleach, mercuric chloride, and sodium hypochlorite.

Callus induction- A prerequisite for obtaining cells or clumps of cells in the liquid medium is the establishment of callus cultures. Callus is an undifferentiated mass of cells, which can transform into any other cells upon plant growth regulator modifications.

Establishment of suspension culture

The callus is cut into small pieces and transferred to the liquid medium with appropriate growth hormones. The flasks containing callus are kept on the rotatory shaker to agitate the cells. Initially, the speed of the shaker is kept high to break the clump of cells into smaller pieces and after that, the speed is lowered to maintain the uniformity in the nutrients and aeration in the cells. The cells are periodically transferred to the fresh media with a similar composition for enhanced growth.

Figure 1: a) Callus on solid medium b) callus in the liquid medium c) establishment of suspension culture

Growth dynamics

Understanding cell proliferation and differentiation as well as maximizing the production of bioactive compounds depend heavily on the growth dynamics of cell suspension cultures. Studying different growth stages, analyzing biomass accumulation, and monitoring changes in metabolic activities are all necessary for comprehending these processes. Generally, there are three phases in the normal growth of cells, lag phase, log phase, and stationary phase.

Lag Phase- The cells are adapting to the changed environment and there is little or very little cell division takes place. This phase is mainly characterized by cellular adjustments, such as metabolic adaptation and enzyme induction. the length of this phase can vary and depend on the media composition and amount of initial inoculum of the explant.

Log Phase- It is also known as the exponential phase, because of the rapid growth of the cells. metabolic activities and cell division remain very high in this period.

The cells cease to grow after exhausting all the nutrients and accumulation of the waste material.

Stationary Phase- The cells' growth stops due to nutrient exhaustion and waste accumulation. Cells reach equilibrium where the rate of cell growth equals the rate of cell death.

There are different parameters to evaluate the growth dynamics of cells biomass estimation, cell viability, nutrient uptake, pH, and electrical conductivity.

Cell viability and density

Cell viability can be traced by staining the cells with dye (Trypan blue, Evans blue, etc.) and analyzing them under the microscope or counting the cells using a hemocytometer. The cell density can be calculated by packed cell volume and settled cell volume.

Biomass accumulation

Biomass is measured by calculating fresh weight and dry weights after a certain time interval. Cells are collected, dried in the oven, and then weighed for dry weight.

pH and EC

These two factors influence nutrient availability, cell metabolism, and overall culture health. Since the availability and solubility of nutrients are pH dependent, also the enzymes involved in metabolic activities have an optimal pH range where they perform better. pH and EC are monitored through the pH meter to achieve consistent and scalable results.

Scale up production

In the laboratory, these cultures are kept in small flasks, to scale up the production of secondary metabolites; large industrial-size bioreactors are used. They are used for large-scale production and are equipped with sophisticated sensors, bioreactors, and aeration technology. Consistent and sterile nutrient supply is maintained by batch-fed or continuously growing cultures. The general capacity of pilot intermediate plants is 5-20 liters whereas the industrial scale bioreactors can perform reactions of 100 L to several thousand liters capacity.

Applications of cell suspension culture pharmaceuticals

Production of anti-cancer agents (Zhong, 2001)

Taxus brevifolia is known for its anti-cancer properties. Taxol or paclitaxel is derived from this plant and exhibits anti-proliferative properties (Wickremesinhe&Arteca, 1994). CSC is a sustainable and efficient method to extract important compounds from the plants.

Camptothecin is like several other compounds extracted from plants by using bioreactors.

Production of antimalarial drugs

Artemisinin and Quinine both are known for their anti-malarial properties and areproduced at a very huge scale in bioreactors using CSC (Keng et al., 2007).

Production of cardioactive drugs

Digoxin and Digitoxin arecardiac glycosides produced from Digitalis species and are produced at the industrial level using CSC (Hong et al., 1998).

Production of several important drugs like anti-viral, anti-oxidants, anti-inflammatories, and analgesics are produced in the bioreactors.

Nutraceuticals and cosmetics

Hyaluronic Acid is the new talk of the town in terms of moisturizers and certain bacterial strains and plants produce hyaluronic Acid. Plant cells can be engineered to produce more collagen (anti-aging agent). Anti-oxidants like Resveratrol and Catechins can be produced at large scale using CSC. Several compounds are involved in and as immunity boosters, digestive, heart, and joint health are synthesized at a huge scale using CSC.

Research and development

Enhancement of the production of metabolomics through metabolomic engineering and identification, quantification, and characterization of secondary metabolites to reveal their biological functions and potential benefits are some new avenues of plant biotechnology where CSC is being explored (Xu et al., 2011).

Conclusion

CSC is an effective tool that makes it feasible to produce significant biochemical compounds efficiently and sustainably. Notwithstanding these obstacles, further study and technical developments keep this approach more feasible and scalable. As a result, cell suspension culture holds great promise for contributing to pharmaceuticals, nutraceuticals, cosmetics, agriculture, and environmental sustainability, ultimately enhancing our ability to harness the full potential of plant-derived secondary metabolites.

References

Xu, J., Ge, X., & Dolan, M. C. (2011). Towards high-yield production of pharmaceutical proteins with plant cell suspension cultures. *Biotechnology advances*, *29*(3), 278-299.

Zhong, J. J. (2001). Biochemical engineering of the production of plant-specific secondary metabolites by cell suspension cultures. *Plant cells*, 1-26.

Keng, C. L., Singaram, N., & Lim, B. P. (2007, June). Production of artemisinin from cell suspension culture of Artemisia annua L. In *Proceedings Asia Pacific Conference on Plant Tissue and Agribiotechnology (APaCPA) Vol* (Vol. 17, p. 21).

Hong, H. J., Lee, J. E., Ahn, J. E., & Kim, D. I. (1998). Enhanced production of digoxin by digitoxin bio transformation using in situ adsorption in Digitalis lanata cell cultures. *Journal of microbiology and biotechnology*, *8*(5), 478-483.

Wickremesinhe, E. R., & Arteca, R. N. (1994). Taxus cell suspension cultures: optimizing growth and production of taxol. *Journal of Plant Physiology*, *144*(2), 183-188.

Battling *Lantana camara*: Management and restoration efforts in Gujarat and Rajasthan

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Introduction

Lantana camara, an invasive shrub native to Central and South America, has emerged as a formidable ecological menace in various parts of the world, including India. This species has caused substantial challenges for biodiversity, agricultural productivity and ecosystem services in Gujarat and Rajasthan. In Gujarat's Gir Forest, the last stronghold of the Asiatic lion, the dense thickets of *Lantana camara* hinder the growth of essential grasses, posing a severe threat to the herbivores that form the lion's primary prey base. This disruption in the food chain not only endangers the herbivores but also jeopardizes the lion population, leading to broader ecological imbalances.Similarly, in Rajasthan, regions such as the Aravalli hills and numerous wildlife sanctuaries are grappling with the invasive spread of *Lantana camara*. The plant's aggressive growth leads to the displacement of native vegetation, which is critical for sustaining the local wildlife, including several endangered species. The loss of this native flora impacts the habitat quality and food availability for various fauna, further stressing the fragile ecosystems.

Moreover, the Thar Desert, known for its unique and delicate ecological balance, is significantly affected by the proliferation of *Lantana camara*. The invasive shrub alters soil composition and water retention capabilities, disrupting the natural habitat conditions that many endemic species rely on. This leads to a decline in the desert's biodiversity and affects its ecological functions.This article delves into the management strategies employed to control *Lantana camara*, the restoration efforts aimed at rehabilitating affected areas and the overall ecological impacts of this invasive species in Gujarat and Rajasthan. By understanding these aspects, we can better appreciate the ongoing efforts and the challenges involved in mitigating the adverse effects of *Lantana camara* on these critical ecosystems.

Fig 1- Flowers and Leaves of *Lantana Camara*

Ecological Impact of Lantana camara

Lantana camara, a highly invasive shrub, significantly disrupts ecosystems by displacing native flora and altering habitat structures. Its dense thickets prevent the growth of understory vegetation, leading to a decrease in biodiversity. This invasive plant creates monocultures, thereby reducing the diversity and resilience of local ecosystems. In Gujarat and Rajasthan, *Lantana camara* has a particularly detrimental impact on several native plant species, which in turn affects the animals that depend on these plants for food and shelter. Additionally, it modifies soil chemistry and hydrology, making it difficult for native species to re-establish once *Lantana camara* is removed.

Impact in Gujarat's Gir Forest

In Gujarat's Gir Forest, the spread of *Lantana camara* has caused significant habitat degradation. Gir Forest is the last stronghold of the Asiatic lion, and the invasive spread of *Lantana camara* poses a serious threat to this iconic species. The dense thickets of *Lantana* inhibit the growth of grasses and other native plants that are essential for the herbivores in the region, such as deer and antelope. These herbivores form the primary prey base for the Asiatic lions. The reduction in food availability for herbivores leads to a decline in their populations and overall health.As herbivore populations dwindle, the food chain is disrupted, impacting the lion population directly. Lions depend on these herbivores for sustenance and any decline in prey availability threatens their survival. This creates a ripple effect throughout the ecosystem, leading to imbalances that can have far-reaching consequences. For example, with fewer herbivores to graze on grasses, certain plant species might become overgrown, further altering the habitat and making it even less suitable for a diverse range of wildlife.

Impact in Rajasthan

In Rajasthan, the situation is equally dire. Areas such as the Aravalli hills and various wildlife sanctuaries have reported significant invasions of *Lantana camara*. These regions are known for their unique biodiversity and host a variety of flora and fauna, including several endangered species. The aggressive spread of *Lantana camara* leads to the loss of native vegetation, which is crucial for the survival of local wildlife. Native plants provide essential food and habitat for many species; when these plants are displaced by *Lantana*, the entire ecosystem suffers.For instance, many insect species rely on native plants for nectar, pollen and as host plants for their larvae. When these plants are replaced by *Lantana camara*, insect populations can decline, which in turn affects the animals that feed on them, such as birds and small mammals. This disruption of the food web can lead to further declines in biodiversity.

Impact on the Thar Desert

The Thar Desert, known for its unique and fragile ecosystem, is also significantly impacted by *Lantana camara*. The invasive plant disrupts the delicate balance of the desert environment by altering soil composition and water retention properties. The Thar Desert is characterized by its arid conditions, where native plants have adapted to survive with minimal water and nutrient-poor soils. *Lantana camara*, however, can alter the soil's physical and chemical properties, making it less suitable for native desert plants.These changes can lead to a reduction in the diversity of plant species that can survive in the desert. This, in turn, affects the animals that depend on these plants for food and shelter. For example, certain bird species that nest in native shrubs may find fewer suitable nesting sites, leading to declines in their populations. Similarly, herbivores that feed on native plants may struggle to find enough food, affecting their health and reproduction rates.Furthermore, the presence of *Lantana camara*can alter the hydrology of the desert. Native plants are typically well-adapted to the desert's water regime, but *Lantana camara's* different water uptake patterns can change the availability of water in the soil, impacting other plant species. This can lead to further degradation of the desert ecosystem, making it even more vulnerable to the impacts of climate change and other environmental stressors.

Management Strategies

Mechanical Removal

Manual and mechanical removal of *Lantana camara*is a widely used method to manage this invasive species. This process involves physically uprooting and cutting the shrubs, followed by burning or composting the biomass. Mechanical removal can be effective in small areas or specific sites where precision is needed. However, this method is labor-intensive and often requires repeated efforts due to the shrub's high regrowth potential. The resilience of *Lantana camara* means that even small root fragments left in the soil can regenerate, requiring continuous monitoring and removal efforts. Additionally, mechanical removal can disturb the soil, potentially promoting the spread of other invasive species. Despite these challenges, mechanical removal remains a crucial part of integrated management strategies, especially in protected areas where chemical use might be restricted.

Pic 2- Community members using axes to remove *Lantana camara* in the Udaipur Forest range.

Chemical Control

Using herbicides like glyphosate and triclopyr has proven effective in controlling *Lantana camara.* These chemicals can be applied directly to the foliage or cut stumps of the plants, leading to their death. However, chemical control methods must be carefully managed to avoid harming non-target species and minimizing environmental contamination. Herbicides can leach into the soil and water systems, potentially affecting nearby plants and animals. Therefore, it is crucial to follow guidelines and best practices for herbicide application, including timing and dosage, to ensure the treatment is effective and environmentally responsible. Chemical control is often most effective when combined with other management strategies, reducing the overall chemical load needed for effective control.

Biological Control

Biological control involves introducing natural enemies of *Lantana camara*, such as specific insects and pathogens, to control its growth. In India, some success has been observed with the use of the beetle *Teleonemiascrupulosa*, which feeds on *Lantana* leaves. This method offers a potentially sustainable solution by leveraging natural ecological interactions to keep the invasive species in check. However, the long-term effectiveness and ecological safety of biological control agents require thorough evaluation. There are concerns about the potential for introduced species to become invasive themselves or to negatively impact native species. Rigorous testing and monitoring are necessary to ensure that biological control agents are safe and effective over the long term.

Integrated Management

Combining mechanical, chemical, and biological methods often yields the best results in managing Lantana camara. Integrated management strategies can provide more sustainable control of this invasive species by reducing its regrowth and allowing native species to re-establish. For example, an integrated approach might involve initial mechanical removal to reduce the bulk of the infestation, followed by targeted chemical treatments to address regrowth and the introduction of biological control agents to maintain long-term suppression. This holistic approach leverages the strengths of each method while mitigating their individual limitations. Moreover, integrated management often involves community engagement and education, ensuring that local populations are aware of the ecological impacts of *Lantana camara*and are equipped to participate in ongoing management efforts. Effective integrated management requires ongoing monitoring and adaptive management, as conditions and challenges can change over time. By continuously evaluating the effectiveness of different methods and adjusting strategies accordingly, managers can achieve more resilient and sustainable outcomes in controlling Lantana camara.

Pic 3 – Different control methods and restoration process of *Lantana Camara*

Restoration Efforts

Restoring areas invaded by *Lantana camara* involves reintroducing native species and rehabilitating degraded ecosystems. In Gujarat and Rajasthan, several initiatives have been launched to restore habitats affected by Lantana invasion, focusing on native species planting, community involvement and continuous monitoring and research.

Native Species Planting

Replanting native tree species such as *Tectona grandis*, *Albizia lebbeck*, *Anogeissus latifolia*, *Pongamia pinnata*, *Acacia catechu*, *Syzygium cumini*, *Ficus benghalensis*, *Terminalia arjuna*, *Acacia nilotica*, and *Prosopis cineraria* is crucial for restoring natural vegetation and biodiversity. These plants are chosen for their resilience to local climatic conditions and their ability to outcompete Lantana camara. By reintroducing these native species, the natural structure of the ecosystem can be gradually restored, providing habitat and food sources for native wildlife. This method not only helps in displacing Lantana camara but also strengthens the ecological resilience of the region.

Community Involvement

Engaging local communities in restoration activities is crucial for the success and sustainability of these projects. Community-based programs educate locals on the impacts of *Lantana camara* and involve them in monitoring and maintaining restored areas. This participatory approach ensures that the efforts are locally supported and maintained over the long term. Community involvement also fosters a sense of ownership and responsibility towards the environment, encouraging ongoing stewardship and protection of restored habitats.Monitoring and Research: Continuous monitoring and research are essential to evaluate the effectiveness of management and restoration efforts. This involves studying the ecological dynamics of restored areas, tracking the growth and health of reintroduced native species, and adjusting strategies as needed to ensure long-term success. Ongoing research helps identify best practices and innovative approaches to restoration, ensuring that efforts are adaptive and responsive to changing environmental conditions.

Overall, the combined efforts of native species planting, community involvement, and rigorous monitoring and research form a comprehensive strategy for restoring ecosystems invaded by *Lantana camara*. These efforts are vital for preserving biodiversity and maintaining the ecological balance in Gujarat and Rajasthan.

Conclusion

Managing and restoring areas invaded by *Lantana camara* in Gujarat and Rajasthan are essential for preserving biodiversity and ecosystem health. An integrated approach that combines mechanical, chemical and biological methods, along with active community participation, has proven to be the most effective strategy. This comprehensive approach leverages the strengths of each method while mitigating their individual limitations. Moreover, continuous research and monitoring are crucial to adapt management practices to evolving ecological conditions. This ensures the long-term success of restoration efforts by allowing for adjustments based on ongoing observations and findings. Ultimately, a sustained, multifaceted effort is required to effectively control *Lantana camara* and restore the affected ecosystems, safeguarding the unique biodiversity and ecological balance of these regions.

Unveiling the forest-water nexus: How forests shape the water cycle

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Introduction

The forest and water represents the interconnected and mutually influential relationship between forest ecosystems and water resources. Forests play a pivotal role in regulating the hydrological cycle, impacting the quality, quantity, and timing of water flows. Through processes such as interception, infiltration, and transpiration, forests influence precipitation patterns, groundwater recharge, and the maintenance of water quality.Forests act as natural water filters, trapping sediments, nutrients, and pollutants, thereby ensuring cleaner water downstream. The root systems of trees enhance soil stability, reducing erosion and preventing sedimentation in water bodies. Moreover, the canopy cover provided by forests reduces the velocity of rainfall, minimizing surface runoff and promoting groundwater recharge.

Water, in turn, is essential for the health and growth of forests. Adequate water availability supports the diverse flora and fauna within forest ecosystems and helps maintain the resilience of forests against environmental stressors such as droughts and fires. The forest-water nexus is particularly significant in the context of climate change, where alterations in precipitation patterns and increased temperatures can disrupt this delicate balance, affecting both water security and forest health.Understanding and managing the forest and water nexus is crucial for sustainable natural resource management, ensuring the preservation of ecosystem services and the well-being of human communities dependent on these vital resources.

Tree -Water Interactions

Evapotranspiration

Plant transpiration represents on average 60% of terrestrial evapotranspiration and, therefore, significantly contributes to the global water cycle.Trees contribute to evapotranspiration, a combined process involving the loss of water through evaporation from the soil surface and rainwater trapped on leaves, as well as transpiration, where water is transferred from the roots to the leaves and released through the leaf surface. These processes occur simultaneously, with the evapo-transpiration moisture playing a key role in enabling precipitation.

Fig 1: Benefits of tree withrespect to water

Infiltration and groundwater recharge

Tree roots, along with enhanced levels of soil organic matter from litter inputs, improve soil structure and its water infiltrating capacity. This results in better infiltration of water into the soil, promoting groundwater recharge.

Precipitation formation

Trees release biological particles such as spores and pollen into the atmosphere. These particles attract atmospheric moisture, facilitating cloud formation and subsequently, rainfall.

Fog/Cloud trapping

Trees, especially those at high altitudes, can collect additional moisture from clouds and fog. This moisture then contributes to infiltration and groundwater recharge, enhancing water availability in these regions.

Understanding these interactions is essential for managing forest ecosystems and water resources effectively, as they highlight the integral role trees play in the hydrological cycle.

Flood moderation

Trees and their impact on soil significantly reduce the speed and quantity of stream flows and decrease erosion in local catchments. Forests play a crucial role in water capture areas by mitigating the effects of floods.

The water cycle is often considered a single concept, but it actually consists of two interdependent cycles that vary in temporal and spatial scales. The Short (Closed) Water Cycle pertains to the local circulation of water above continents or oceans, while the Long (Open) Water Cycle involves water movement between continents and oceans. Forests play a crucial role in both cycles by storing and transporting significant amounts of water. They help regulate the timing of water flows, impacting local and global climates. By influencing both cycles, forests contribute to the stability and sustainability of the water cycle overall.

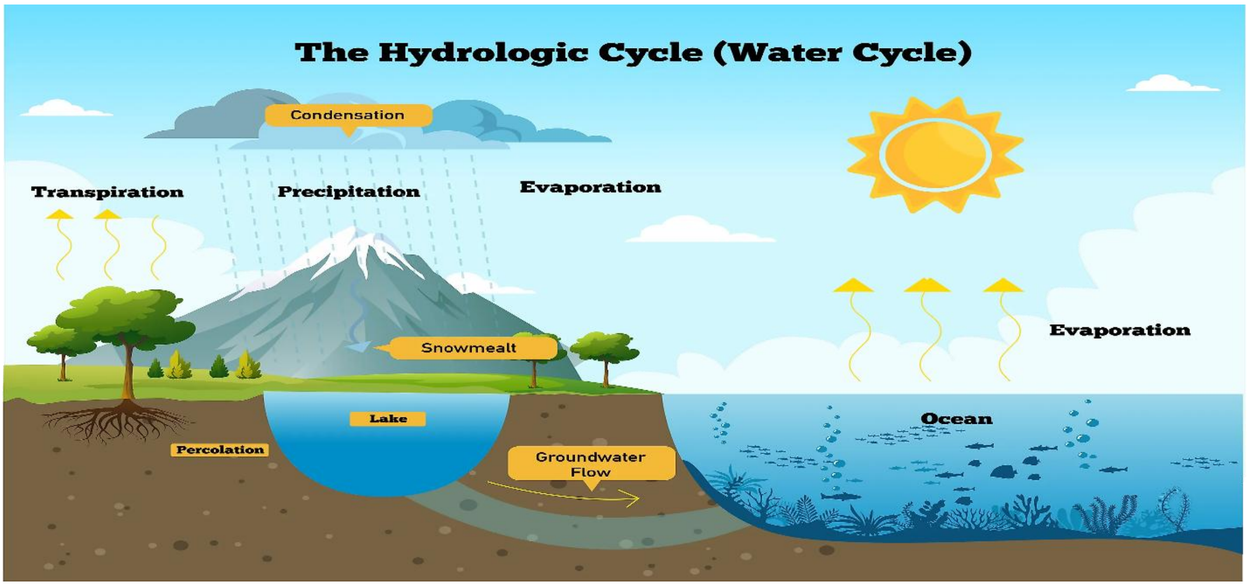

Fig 2: Influence of tree on water cycle

Influence on water quality, quantity, and timing

Forests significantly influence water quality, quantity, and timing, despite the complexities of the water cycle.

Water quality

Forests act as natural filters, purifying water by removing sediments, nutrients, and pollutants. Forest management practices directly affect drinking water quality both locally and downstream. The regulation of water quality is one of the most vital ecosystem functions of forests. Nearly 800 million people lack basic drinking water services, and at least 2 billion people use unsafe drinking water sources that can cause diseases like diarrhea, cholera, dysentery, typhoid, and polio.

Water quantity and timing

Water flow is not consistent throughout the landscape and is influenced by several factors, including climate, topography, land cover, and soils. Climate factors such as total rainfall amount and intensity, topography elements like slope gradient and length, vegetation type and density in land cover, and soil texture and structure all play critical roles in shaping watercourses and affecting groundwater and soil saturation. Forest cover intercepts and slows runoff, increases infiltration, and enhances evapotranspiration, providing crucial water regulation services. In contrast, cleared, hard, or built-up areas lack these capabilities, making them more susceptible to flooding and erosion. The relationship between forests and water quantity and timing is highly contextual, with many trade-offs to consider. Further exploration of these trade-offs is necessary to fully understand the complexities of forest-water interactions.Forests as Water Users and Water Recyclers

Forests: Dual role as water consumers and recyclers

Forests play dual roles in the water cycle as both consumers and recyclers of water. As living organisms, trees require water for their metabolic processes, which can reduce streamflow downstream due to their water consumption. At the same time, forests contribute to atmospheric moisture and precipitation, enhance groundwater recharge, and maintain soil moisture, effectively recycling water and integrating it back into the water cycle. The water-related services provided by forests vary depending on factors such as scale, age, and type of forest. For instance, peatlands rely on abundant water for the accumulation of peat, making them crucial as the largest terrestrial carbon sink for climate change mitigation. They also provide biodiversity habitats, act as natural water filters, and aid in flood mitigation. However, draining peatlands for agriculture exposes peat, leading to rapid decomposition and carbon release, which undermines these benefits. Other forest ecosystems, such as dryland forests, cloud forests, and mangroves, each offer unique water-related advantages and support diverse forms of biodiversity.

Benefits from forest-water relationships

The interactions between forests and water yield numerous ecosystem services, which can be categorized into environmental, economic, and sociocultural aspects. Environmentally, forests regulate water quantity and timing through interception, infiltration, and evapotranspiration. They enhance groundwater recharge by improving soil structure with tree roots and organic matter, generate clouds through evapotranspiration, purify water by filtering sediments, nutrients, and pollutants, and reduce soil erosion and sedimentation in water bodies. These benefits underscore the critical role forests play in maintaining water quality, regulating water flows, and supporting ecosystem health, essential for environmental sustainability and human well-being. Economically, forests provide valuable resources such as timber, fruits, nuts, and medicinal plants, contribute to the availability of clean water for domestic and industrial uses, protect coastlines from erosion and storm surges through mangrove and coastal ecosystems, and enhance soil fertility for agriculture. Socioculturally, forests hold deep spiritual and cultural significance for many communities, particularly indigenous peoples, offer recreational opportunities that promote mental and physical well-being, and foster social cohesion by serving as communal spaces for gatherings, education, and cultural activities. These diverse benefits highlight the multifaceted value of forests in supporting both human and environmental health.

Conclusion

The ability of forests to provide crucial water-related ecosystem services cannot be underestimated. Forests naturally filter nutrients, reduce soil erosion, and mitigate sedimentation, ensuring high water quality. They regulate water quantity and timing by slowing runoff and increasing infiltration and evapotranspiration. Forests are vital for water access in watersheds, providing fresh water for human consumption and agriculture. Beyond environmental benefits, forests offer significant economic and sociocultural advantages. Many communities, including indigenous peoples, urban centers, and agricultural communities, depend on forest-water relationships for their livelihoods, sustenance, and well-being. The spiritual and cultural connections of local communities to these ecosystems are often integral to their identity and livelihoods. Recognizing and preserving these relationships is essential for sustainable development and the resilience of both natural and human systems.

Reference

Bachofen, C., Tumber-Dávila, S. J., Mackay, D. S., McDowell, N. G., Carminati, A., Klein, T., ... & Grossiord, C. (2024). Tree water uptake patterns across the globe. *New Phytologist*, *242*(5), 1891-1910.

Bonnesoeur, V., Locatelli, B., Guariguata, M. R., Ochoa-Tocachi, B. F., Vanacker, V., Mao, Z., ... & Mathez-Stiefel, S. L. (2019). Impacts of forests and forestation on hydrological services in the Andes: A systematic review. *Forest Ecology and Management*, *433*, 569-584.

Creed, I. F., & van Noordwijk, M. (2018). Forest and water on a changing planet: vulnerability, adaptation and governance opportunities. A global assessment report.

Sellers, P. J., Dickinson, R. E., Randall, D. A., Betts, A. K., Hall, F. G., Berry, J. A., ... & Henderson-Sellers, A. (1997). Modeling the exchanges of energy, water, and carbon between continents and the atmosphere. *Science*, *275*(5299), 502-509.

Wei, Z., Yoshimura, K., Wang, L., Miralles, D. G., Jasechko, S., & Lee, X. (2017). Revisiting the contribution of transpiration to global terrestrial evapotranspiration. *Geophysical Research Letters*, *44*(6), 2792-2801.

Economic and ecological potential of medicinal plant based agroforestry system

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Abstract

Medicinal plants are essential to people's health and well-being. In the past as well as present a lot of people relied on plant-based treatments to treat illnesses in humans, plants and animals. World Health Organization (WHO) estimates that 80 percent of the world's population currently receives basic healthcare from traditional medical systems. This tilt is frequently caused by annoying side effects and a lack of therapeutic benefit in modern medicine. Agroforestry has become a vital land management strategy due to the growing demand for herbal products. It offers a variety of products, including food, fodder, fruit, fiber, pulp and medicinal products, for both trade and consumption.By incorporating Medicinal plants into the agroforestry system, concerns of conservation can be addressed. Promotion of these plant species cultivation seems to be a key tactic for reducing the harvest strain on wild populations. Also, Agroforestry as an integrated land use management system supports livelihood by providing medicinal plants for consumption along with reduction of environmental degradation and act as a carbon sink.

Keywords: Agroforestry, Medicinal plants, Environment, Economic

Introduction

Plant-based medicines have been a part of Indian medicine since the Vedic era, as evidenced by the literature of Jivaka, Charaka, and the Ramayana. All ancient civilizations, including those of the Indus Valley, Mesopotamia, and China, relied on medicinal herbs to ensure the health of their human, livestock, and plant populations. Medicinal plants were employed in medicine for rituals and beliefs, as well as for prevention and treatment. Humans relied only on plants to treat illness before the development of modern medicine. The Indian medical systems of "Ayurveda," "Siddha," and "Unani," as well as "Homoeopathy," partially, rely on plant materials or their derivatives to cure human illnesses (Prajapati *et al*. 2003). The contemporary medical system is expensive and out of reach for people living in rural and isolated places, thus they mainly rely on traditional medicine. For the steadfast belief that they are more successful than contemporary medications for specific chronic diseases, the fact that they lack some of the adverse effects that some modern medications do, or for financial considerations, many industrialized and developing nations turn to traditional medicine. The value of MAP (Medicinal and Aromatic plants) has expanded recently due to its use in the cosmetic and perfume industries, as well as dietary supplements. The demand for MAP is rising as a result of people's global insistence on leading natural lives. This raises some concerns about MAP's existence in the wild. Its cultivation could provide a sustainable supply and aid in conservation of biodiversity. It is important to encourage MAP species cultivation in order to aid in their conservation in the wild. A strong management system needs to be developed in order to maintain soil health, improve livelihood, and produce medicinal plants continuously while halting climate change.

Agroforestry is a brilliant tactic that combines modern technology with centuries-old knowledge. It is an integrated strategy that offers a viable answer by putting animals, crops, and/or trees all on one piece of land. Recognized as a sustainable approach, it balances environmental preservation with agricultural productivity. In order to address the needs of an expanding population, maintain the sustainability of agroecosystems, combat deforestation, prevent soil degradation, and protect biodiversity, this age-old method has sparked new scientific interest. Agroforestry provides environmental benefits like carbon sequestration and climatic resilience together with tangible products like food, lumber, and other non-timber forest items, all of which contribute to livelihood security. Economically speaking, this method of output diversification raises farmer income, which eventually improves both their standard of living and the state of the national economy. Because it offers a variety of ecosystem services, including food, fodder, fuel wood, fruit, timber, and other non-timber forest products, as well as environmental benefits like watershed protection, carbon sequestration, and mitigation of the adverse effects of climate change, agroforestry is currently being acknowledged as a sustainable land use system.

Medicinal plant-based Agroforestry system

Agroforestry systems centered around medicinal plants can yield a variety of goods for trade and consumption, including food, fodder, fruit, fiber, pulp, and medicinal plants, along with this these systems can conserve biodiversity by lessening the strain on natural resources. Medicinal plants thrive in an agroforestry system in two ways. As overstorey tree in whichtrees may benefit from the inputs and management given to the intercrops or as intercrop under the canopy of taller trees in which intercrops generate income for farmers when the main trees have not started production

Different types of medicinal plant-based Agroforestry system

Agroforestry system	Tree Species	Intercrops
Agrisilvis ystem	*Acacia mangium*	*Pogostemon cablin (Patchouli)*
Agrisilvi system	*Pongamia pinnata*	*Plantago ovata (Isabgol)*
Agrisilvi system	*Eucalyptus*	*Withania somnifera*
Agrisilvi system	*Terminalia*	*Vigna mungo, Maize*

	chebula	
Agrisilvi system	*Phyllanthus emblica*	*Vigna mungo, maize, soybean*
Hortiagri system	*Cocos nucifera*	*Aloe indica, Asparagus racemosus, Kaempferia angustifolia*
Hortiagri system	*Psidium guajava*	*Aloe indica, Asparagus racemosus, Kaempferia angustifolia*
Hortiagri system	*Prunus persica*	*Ocimum sanctum*
Hortiagri system	*Litchi chinensis*	*Zingiber officinale, Curcuma longa, Asparagus officinalis*
Hortiagri system	*Mangifera indica*	*Zingiber officinale, Curcuma longa, Asparagus officinalis*
Hortiagri system	*Manilkara acharas*	*Ocimum sanctum, Andrographis paniculata, Mentha arvensis*
Agrisilvi system	*Jatropha curcas*	*Ocimum sanctum, Andrographis paniculata, Mentha arvensis*

Economic potential of medicinal plant based agroforestry system

Integration of medicinal plants in agroforestry system is strategic driver of economic prosperity. As global interest in natural remedies surges, the cultivation of medicinal plants emerges as economic avenue, fostering diverse opportunities across multiple sectors. In the pharmaceutical industry, these plants serve as invaluable reservoirs of bioactive compound, fueling the production of herbal medicine and pharmaceutical formulations.

Highly profitable to farmer

Cultivating medicinal plants represents a lucrative venture for farmers, interwinding agricultural practices with economic prosperity. The demand for natural remedies and herbal products is escalating globally, creating a burgeoning market that smart farmers can tap into for substantial financial gains. Additionally, the sustainable cultivation of medicinal plants in agroforestry system aligns with the growing consumer preference for organic and ethically sourced products further enhancing marketability. Furthermore, the versatility of medicinal plants allows for value addition through the production of essential oils, extract and herbal formulations. This also opens avenues for establishing small-scale processing units, fostering entrepreneurship within farming communities. B:C ratio of some medicinal plants under agroforestry system shows highest economic return than mono cropping as shown below in Table.

Agroforestry System	**B:C ratio**	**References**
Coconut + Guava +Misridana	5.06	Bari and Rahim, 2012
Psidium guajava + *Curcuma longa*	4.74	Chandra, 2014
Manilkara acharas + *Jatropha curcas* + Basil	1.67	Solanki *et al.* 2014

Sapota+ Grass + *Dalbergia sissoo* + Maize + sun hemp	1.22	Patil *et al*. 2010
Coconut + Guava + Lemon + Asparagus	3.08	Bari and Rahim, 2012
Peach + *Ocimum sanctum*	1.87	Sharma *et al*.2021

Changing customer preference towards natural alternatives

From demand & growth trends it has been estimated that preference of customers is changing toward natural alternatives. Common reasons for this tilt are frustrating side effects and lack of curative value in modern medicine. With growing population demand is increasing day by day but production of medicinal and aromatic plants is decreasing. According to WHO, the international market of herbal products is around $6.2 billion which is poised to grow to $5 trillion by the year 2050. Unfortunately, India's share in the global medicinal plants related export trade is just 0.5% (Kumar *et al.* 2011). So as to meeting the demand of growing population and to give continuous supply of raw material for pharmaceutical industry there is need of increasing the production of MAP. In 2015, the gap between demand and supply of MAPs was predicted to be between 50,000 and 250,000 tons. In 2020, this hole was predicted to grow from 250,000 to 500,000 tons (Rao and Singh, 2023).

Society upliftment

Adoption of medicinal based systems can improve the socio-economic conditions of resource deficient farming community. In addition to providing these farmers with additional money and a significant amount of livelihood support, the produce from trees also ensures the medicinal and nutritional security of people. As the demand for herbal remedies skyrocket globally, the cultivation of medicinal plants help in securing income for farmers and alleviate poverty.

Solution to allelopathic medicines

India has long time legacy of plant-based medicines since Vedic era and also evident from Ramayana epic, Charaka and Jivaka literatures. People in villages and remote areas primarily depend on traditional medicines as the modern system is out of reach and expensive. Many developed and developing countries use traditional medicines because of firm belief that they are more effective than modern medicines for certain chronic disease, do not have side effects as some of the modern medicine has and for economic reasons. Medicinal plants offer a natural reservoir of bioactive compounds that can serve as effective alternatives. These plants contain a myriad of phytochemical with therapeutic properties offering a rich source of developing pharmaceuticals. Phytochemical quality of medicinal plants viz., Ginger (*Zingiber officinale*), Turmeric (*Curcuma longa*) and Asparagus (*Asparagus officinalis*)were evaluated under the floor of litchi-mango based AFS. In this study maximum amount of oil content (3.94%, 4.37%, and 6.45%) were recorded under litchi based AFS while minimum (3.24%, 3.92% and 5.52%) was recorded in sole cropping of medicinal plants (Ali *et al.* 2013).

Contribution in economy of country

India is expected to become the third largest economy in the world with a GDP of $5 trillion in the next three years and touch $7 trillion by 2030. The cultivation of medicinal plants in agroforestry system and export of these plays a pivotal role in bolstering a nation's economy. Extraction of active compounds from these plants not only fuels a robust domestic pharmaceutical industry but also position India as a key player in the international herbal medicine market. Beyond healthcare, cultivation and trade of medicinal plants provide a lifeline to rural economies while supporting livelihood of small-scale farmers and marginalized communities.In India the value of botanicals related trade is about US$10 billion per annum with annual export of US$1.1 billion Medicinal plants valued for their therapeutic properties, attract a robust demand from pharmaceutical and cosmetic industries worldwide. Moreover, the sustainable cultivation of plants promotes environmentally friendly practices, fostering a positive image in international trade.

Ecological potential of medicinal plant-based agroforestry system

Medicinal plants emerge as ecological allies offering a myriad of environmental benefits that extend far beyond their therapeutic properties. Cultivation of medicinal plants in agroforestry system enhances ecological resilience, providing a robust defense against pest, disease and environmental stressors.

Soil Health Maintenance

Medicinal plant cultivation emerges as a boon not just for human health but also as a guardian of soil vitality. Unlike conventional system integration of medicinal plants in agroforestry systems contribute to soil fertility by enhancing microbial diversity and promoting nutrient recycling. Pruned material which is incorporated in soil can maintain soil health, promoting sustainable land use and contributing to the overall health of the ecosystem. It enhances soil organic carbon, improve soil structure, promote nutrient cycling and reduce soil erosion. Furthermore, many medicinal plants exhibit phytoremediation properties absorbing contaminants and pollutants.

Biodiversity conservation

Medicinal plant-basedagroforestry systems can support biodiversity conservation, promoting sustainable land use and contributing to the overall health of the human as well as ecosystem. It provides diverse habitats, protection to various species, maintenance of native flora, fauna and pollinators.

Carbon sequestration

Medicinal trees stand not only as a healer but inclusion of medicinal trees along with agricultural crops can contribute to carbon sequestration, which is essential for mitigating climate change. In agroforestry system where there is integration of woody perennial with crops, trees canopies and extensive root system sequester more carbonfor longer time periods. than monocropping of crops. Diverse ecosystems promote healthier soils, fostering microbial activity that enhances carbon storage in soil which is biggest territorial reservoir of carbon after ocean. It has been estimated that soil contains about Thus, beyond their therapeutic properties, medicinal plants emerge as steadfast allies in the quest for balanced and carbon-neutral future.

Microclimate moderation

Medicinal plant-based agroforestry systems contribute to microclimate moderation, which involves the regulation of temperature, humidity, and wind speed, creating favorable conditions for agricultural production and the well-being of plants, animals, and humans.

Other potential of medicinal plant-based agroforestry system

Conservation of traditional culture and cuisine

Medicinal plants serve as invaluable guardians of traditional culture and cuisine, intertwining heritage with health. Many traditional cultures have a rich history of incorporating medicinal plants into their culinary practices, creating a unique tapestry of flavor and remedies passed down through generations. As communities embrace and celebrate these botanical treasures, they not only safeguard their cultural roots but also inspire a broader appreciation for the vital connection between nature and traditional ways of life. MAP plays an important role not only in our pharmaceutical and nutritional supplements but also conserving our culture and cuisine. Most of the religious practices or rituals are not completed without these**.**

Meeting growing demands

Medicinal plant-based agroforestry system not only addresses the varied health needs of a burgeoning population but also provides a resilient platform for drug discovery and development. Integrating these plants into agriculture systems can contribute to food security and concurrently meeting medicinal requirements thus serves the dual purpose by providing a holistic response to the challenges posed by population growth. Example: Sunflower which is major oil seed crop cultivating in Karnataka, Orissa, Haryana, Maharashtra, and Bihar become leading grower after Russia-Ukraine crisis

Constraints facing in adoption of medicinal plant-based agroforestry system

Cultivation

Agro technology is not available for MAP &Unavailability of QPM (Quality plant material). Issuing license or permit to farmers for growing medicinal plants is a time-consuming process. Lacking of linkages among different stakeholders involved.

Illegal acts

Encroachment by outsiders and illegal collection from wild posing are severe threats to sustainability and ecological balances. These illicit activities not only jeopardize the availability of crucial medicinal resources but also risking long term ecological consequences and depriving future generations from essential natural remedies

Marketing

Unorganized & Large supply chain, dependency on middlemen, facing difficulty in selling the products. Lacking of well-planned marketing infrastructure (market place & technology).Inadequate marketing linkages e.g., Mandies, market place.Lack of marketing intelligence e.g., Assessment of demand, supply base, pricing.

Cultural system

Adoption of traditional medicinal knowledge on preparing herbal medicinal formulations is declining through generations.Traditional knowledge on many less known medicinal plant species has declined rapidly.

Collection

Continued illegal collection from wild led to depletion of many important species. Mostly collected and harvested by untrained persons.

Bio piracy

Biopiracy poses a grave threat to medicinal plants, as it involves the unauthorized exploitation of indigenous knowledge and genetic resources for commercial gains. These practices undermine the rich traditions and expertise of local communities. Exploitation not only robs economic opportunity of indigenous community but also leads to over harvesting, habitat destruction, and loss of biodiversity. Apart from this, different ways and system for awarding Patents on the medicinal Plants in different countries have widened the confusion

Lack of post-harvest management facilities and semi processing unit for value addition

Solution/way forward

Research and development

Development of high yielding varieties and in-depth research enhance the rate of success. Allocate funds for conducting R&D not only to improve varieties of medicinal plants and enhance their availability but also establish their efficacy in various climatic conditions. Develop agrotechnology for high in demand medicinal plants.

Efficient extension services

Efficient communication channel, collaboration and effective extension services are needed in order to channelize the research results from lab to land which gone helpful to farmer in achieving their personal as well as nationally our Sustainable development Goals.

Farmer training and capacity building

Conduct training programs to educate farmers about best medicinal crop for particular region, including planting techniques, pruning, pest management, various combinations of intercrops grown along with medicinal plants for different agroclimatic zone.

Financial support

Provide financial incentives, subsidies, or low-interest loans to small scale farmers in order to encourage farmers to adopt Medicinal-based agroforestry systems. This can help overcome initial investment costs and encourage more farmers to participate.

Developing marketing infrastructure and linkages

A market that is effective competitive, readily available, along with suitable post-harvest and marketing in frastructure, has the ability to meet its main goal of delivering net positive return to the producer (GOI, 2018). Cultivation needs to be linked up with QPM and assured market with minimum support price.

E-commerce platforms

Help in eliminating middlemen and bringing farmers and consumers together directly, online marketplaces can boost earnings.

Fair trade and certification: Farmers can benefit from better prices and ethical sourcing by supporting fair trade practices and sustainability certifications.

Value chain development

Creating processing facilities, cold storage facilities, and cooperatives must ensure the purity and safety against microbial contamination and quality deterioration.

For Illegal collection

For addressing this issue there is a need of multifaceted approach combining regulatory measures, community engagement and sustainable practices. Empowering local communities with rights over their traditional knowledge and resources fosters a sense of ownership and responsibility. Implementing guidelines for ethical collection, including proper identification, selective harvesting and resecting seasonal cycles ensures the longevity of medicinal plant populations. Formulation and enforcement of more act like Wildlife Protection act (WPA,1972), Biodiversity act (BDA,2002)

Conclusion

MAP having an important role in people's healthcare and wellness in developing as well as developed world. The use of plant products as nutrition supplements and in the cosmetic and perfume industry has increased the value of medicinal plants in recent years. People around world insisting on natural way of life, consequently demand of MAP is increasing. This growing demand is posing some problem of existence of MAP in wild. Its cultivation may be some answer for sustainable supply and also help to preserve diversity. For developing the "herbal industries", India possesses a rich diversity of medicinal plant speciesacross the various forests along an altitudinal gradient. To support MAP species conservation in the wild its cultivation should be promoted. Apart from growing as a sole crop on agricultural farm, alternative land use system such as agroforestry can be better alternative to cultivate it. MAP is well adapted in forest ecosystems for their requirement for light, temperature, moisture, soil characteristics etc. so they can be accommodated in many tiers of agroforestry system. MAP intercropping with new plantations of coffee, tea, banana, coconut, palm, rubber, apple, mango and cacao offer scope for cultivation of forest medicinal trees that are in demand. It is imperative that this effort should be supported by research on agronomic practices of MAP species and their improvement in traditional, existing as well as new agroforestry system

References

Ali MF, Hanif MA, Bari MS, Akher SA and Fatema U. 2013. Phytochemical assessment of some medicinal plants under different agroforestry system. *Bangladesh research publications Journal*.8(4):186-190.

Bari MS and Rahim MA. 2012. Economic evaluation and yield performance of some medicinal plants in Coconut based Multistoried Agroforestry Systems. *A scientific Journal of Krishi Foundation.* 10(1):71-80

Chandra KK. 2014. Evaluation of growth and economic parameters of *Curcuma longa* and *Amorphophallus paeonifolius* intercrops in medium aged *Psidium guajava* orchard.*Caribbean Journal of Science and technology*.2(1): 392-398.

GOI. 2019. Exports of herbs and herbal products. Ministry of Commerce & Industry. pib.gov.in.

GoI.2018. Operational guidelines Agricultural Marketing Infrastructure sub scheme of ISAM. Ministry of Agriculture and Farmer Welfare, GoI.63pp.

Kumar MR and Janagam D. 2011. Export and Import pattern of medicinal plants in India. *Indian Journal of science and technology*. 4(3): 245-248

Patil SJ, Mutanal SM, Patil HY, Shahapurmath G, Maheswarappa.2010. Performance of Sapota- Teak based agroforestry system in hill zone of Karnataka. *Indian Journal of Agroforestry*.12(1) 27-34.

Prajapati ND, Purohit SS, Sharma AK and Kumar TA. 2003. Handbook of Medicinal Plants. Jodhpur: Agrobios,

Sharma S, Pant KS, Dev Kapil D. 2021. Economic analysis of Ocimum sanctum under peach and apricot based agroforestry system. *Journal of Pharmacognosy and Phytochemistry*. 10(1):93-96.

Solanki VK, Jadeja DB and Tandel MB. 2014. Performance of herbal medicinal crops under Sapota-Jatropha based three-tier agroforestry system. *International Journal of Agricultural Sciences*. 10(1):267-271

Microgreens: The future of sustainable and nutritious food

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Introduction

Throughout human civilization, food has been essential for providing calories and vital nutrients, crucial for growth, development, and survival. Beyond mere sustenance, foods have historically been utilized to prevent and treat various health issues. Food science and nutrition fields have evolved alongside humanity, drawing insights from medicine, biology, and biochemistry to advance our understanding. Nutrigenomics and nutrigenetics methodologies are propelling research forward in this area. While the focus of food and nutrition once centered on preventing deficiencies in vitamins and minerals, it has now shifted toward addressing excesses, such as chronic disorders like obesity. This shift reflects a long history of science-based progress. A growing interest in diet-microbiome interaction has surged, aiming to understand how an individual's microbiome influences health outcomes. Consumer interest in health promotion has driven the demand for better food options, such as those low in fat and calories and high in health-promoting qualities like antioxidants and pro-prebiotics. Although the exact mechanisms are not yet fully understood, this trend has set the stage for the emergence of novel foods with potential health benefits, such as microgreens.

Microgreens are young vegetables typically harvested 10 to 14 days after sowing, reaching a size of one to three inches. They comprise three components: a central stalk, two juvenile true leaves, and cotyledon leaves. However, not all young vegetable greens qualify as microgreens. They are harvested later than sprouts but are smaller than baby greens. The primary distinction among microgreens, baby greens, and sprouts lies in their harvest time. Baby greens are usually picked at 2 to 4 inches after 15 to 40 days, while microgreens are harvested as soon as their smallest leaves appear. Sprouts, in contrast, are harvested even earlier. Additionally, unlike sprouts, microgreens are harvested without their roots. This longer growth period gives microgreens their delicate textures and unique flavors.Microgreens are also notable for their vibrant colors, making them popular as toppings for salads, soups, plates, and sandwiches. The local industry notes that San Francisco, California chefs began using microgreens as early as the 1980s, initially offering limited options like beets, kale, cilantro, arugula, and basil. Today, a wide variety of microgreens are available in the U.S. from numerous growers and seed companies Treadwell *et al.*, *(*2010). Research indicates that 25 commercially available microgreens can enhance the flavor of novel food products, Broccoli, lettuce and chicory, arugula, basil, fennel, carrots, sunflower, radish, peas, and others. Broccoli plays a significant role in the development of the microgreens market due to its extensive health and nutritional benefits. According to the Food and Agriculture Organization.The global microgreens market is projected to grow at an annual rate of 7.6%, reaching a value of US$ 17,039.744 million by 2025.

Bioactive Compounds in Microgreens

Microgreens are rich in bioactive compounds, including vitamins, minerals, and phytochemicals, which are crucial for human health. Studies have shown that microgreens often contain higher concentrations of antioxidants compared to their mature counterparts, though results vary by species.

Vitamin C (VC)

It is essential for wound healing, collagen synthesis, and immune regulation. Found in higher concentrations in certain microgreens like jute and cucumber compared to their mature stages.VC content in microgreens ranges from 20.4–147.0 mg/100 g FW, often higher than in mature plants.

Minerals

Trace minerals such as copper (Cu), zinc (Zn), and selenium (Se) are important for the body's antioxidant defense mechanism.Microgreens generally have higher mineral contents than their mature counterparts. For instance, Zn content in microgreens can be up to 3.2 times higher.

Phytochemicals

Carotenoids (e.g., β-carotene, lutein) and phenolics are abundant in microgreens. Carotenoid content in microgreens can be significantly higher than in seeds. For example, wheat microgreens increase from 0.42 mg/100 g DW to 53.36 mg/100 g DW. Microgreens possess more complex polyphenol profiles and higher phenolic content than mature plants.

Microgreens have a higher Nutrient Quality Score (NQS) due to their elevated levels of vitamins, minerals, and phytochemicals.For example, cauliflower Microgreens show a six-fold higher NQS than their mature stage, mainly due to higher levels of vitamins A and E and carotenoids.

Microgreens production methods and growing media

Microgreens can be produced in various environments, including open air, protected environments, and indoors, using different growing systems such as soil and soilless methods. Containerized production, adaptable for both micro-scale urban and large-scale commercial operations, allows for the commercialization of microgreens while still growing on the media, enabling end users to harvest them directly. This method bypasses many postharvest handling issues, ensuring freshness and high quality Di Gioia *et al.* (2015).

The growing media for microgreens should have a pH of 5.5 to 6.5, low electrical conductivity (<500 mS/cm), optimal water holding capacity (55-70% v/v), and aeration (20-30% v/v) (Abad, Noguera, and Bures, 2001). Peat and peat-based media are commonly used for microgreens production. Coconut coir is an alternative derived from a renewable resource but has variable physicochemical properties and often high salt content and high fungal and bacterial counts.Synthetic fibrous media, such as rockwool or polyethylene terephthalate (PET), developed specifically for microgreens, pose disposal problems.

Natural fiber-based media, such as food-grade burlap made from recycled jute fibers, are also available commercially for microgreens. Low-cost alternatives of natural and renewable origin, like cellulose pulp, cotton, jute, kenaf, and sunhemp fibers, and mixtures of these materials with desirable properties, constitute potential growing media for microgreens Di *Gioia et. al., (*2016*)*. These media can be fortified to improve the nutritional value of or inoculated with beneficial microorganisms to stimulate plant growth or control pathogens Pill Collins*et al.*, (2011).

Most species of microgreens are harvested when the first true leaves appear, with fully expanded cotyledons that are still turgid and retain their typical color. Seedlings are usually 5 to 10 cm in height at harvest. The harvest is performed by cutting the seedlings a few millimeters above the growing media surface, either manually or mechanically.

Key factors in microgreen production temperature

Increasing temperatures from 14°C to 22°C can reduce harvest time by 35-40%.

Planting density

Varies by species and harvest stage, ranging from 1 seed/cm² for larger seeds like pea shoots and sunflower to 10 seeds/cm² for smaller-seeded varieties. Higher seeding densities can increase total yield but decrease individual plant weights.

Substrates and irrigation

Microgreens can be grown on various substrates, including perlite, vermiculite, peat-based mixes, synthetic mats, and hydroponic systems. Substrate depth impacts yield; deeper substrates (1.75 cm to 6 cm) generally result in higher fresh weights. Germination can occur on benches with overhead or sub-irrigation or in germination chambers.

Lighting

Microgreens are commonly grown in greenhouses but can also be produced in growth chambers under artificial light. Supplemental lighting, such as HPS or LED arrays, is essential in low-light conditions (below 10-12 mol/day/m²). Optimum photosynthetic photon flux (PPF) ranges from 330 to 440 µmol/m²/s, with too low or high PPF affecting biomass and antioxidant levels negatively. Blue light at the end of production can enhance carotenoids and glucosinolates, while mixed results are obtained with red light.

Fertilization

Minimal fertilization is needed due to the short production cycle. A combination of pre-plant calcium nitrate and post-plant liquid fertilizers can enhance fresh weight. Spent brewer's yeast and ascorbic acid have also been shown to improve growth and fresh weight.

Sanitation and pathogen control

Maintaining high sanitation standards is crucial to prevent microbiological contamination and exclude insects and diseases. Alternatives to traditional pesticides include Trichoderma species application and the use of beneficial bacteria like Herbaspirillum for disease resistance and growth promotion.

Seed treatment

Seed priming methods, including treatments with sodium hypochlorite or hydrogen peroxide, can improve germination and shoot dry weights. Effective seed treatments to promote growth and combat seedling pathogens are limited but can significantly impact yields and plant health.

References

Abad, M., Noguera, P., & Bures, S. (2001). National inventory of organic wastes for use as growing media for ornamental potted plant production: case study in Spain. Bioresource technology, 77(2), 197-200.

Di Gioia, F., De Bellis, P., Mininni, C., Santamaria, P., & Serio, F. (2017). Physicochemical, agronomical and microbiological evaluation of alternative growing media for the production of rapini (Brassica rapa L.) microgreens. *Journal of the Science of Food and Agriculture*, *97*(4), 1212-1219.

Di Gioia, F., Mininni, C., & Santamaria, P. (2015). Come coltivare micro-ortaggi. How to grow microgreens. Cómo cultivar micro-hortalizas. In *Microgreens: novel fresh and functional food to explore all the value of biodiversity* (pp. 51-80). Eco-logica.

Pill, W. G., Collins, C. M., Gregory, N., & Evans, T. A. (2011). Application method and rate of Trichoderma species as a biological control against Pythium aphanidermatum (Edson) Fitzp. in the production of microgreen table beets (Beta vulgaris L.). *Scientia Horticulturae*, *129*(4), 914-918.

Treadwell, D.D., Hochmuth, R., Landrum, L., Laughlin, W., 2010, Microgreens: A new speciality crop (p.HS1 164). University of Florida, IFAS Extension, https://edis.ifas.ufl.edu/publication/HS1164.

Ecosystem and ecosystem services

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Abstract

An ecosystem is a community or group of living organisms that live in and interact with each other and the non-living parts in a specific environment. All types of ecosystems fall into one of two categories viz. terrestrial and aquatic. Major types of ecosystems are forest, grassland, desert, tundra, fresh water and marine. Healthy ecosystems clean our water, purify our air, maintain our soil, regulate the climate, recycle nutrients, and provide us with food and other raw materials and resources for medicines and other purposes. They are at the foundation of all civilization and sustain our economies. In the present article, we have discussed about the types, structural components and ecosystem services in some length.

Introduction

An ecosystem is a system that includes all living organisms (biotic factor) in an area as well as its physical environment (abiotic factor) functioning together as a unit. The term was first introduced by Tinsley (1935) to encompass the interaction among biotic and abiotic components of the environment at a given site. It is a community of living creatures (plants, animals including human and microorganisms) in a certain region. Each member of the ecosystem interacts with each other and the non-living parts of its environment such as air, water, soil, climate and geographic features. Specifically, an ecosystem is a geographic area where plants, animals and other organisms as well as weather and landscape work together to form a bubble of life (Chapin and Stuart 2011). In a more elaborate form, , an ecosystem may be defined as a structural and functional unit of the biosphere comprising living organisms and their non-living environment that interact by means of food chains and chemical cycle resulting in energy flow, biotic diversity and material cycling to form a stable , self supporting system. For example, tropical forests are ecosystems made up of living beings such as trees, plants, animals, insects and microorganisms that are in constant interactions between themselves and that are affected by other physical (Sun, temperature, humidity, soil, rocks etc) or chemical (oxygen and nutrients) components. However, Odum (1971) in the present accepted form defined ecosystem as an unit that includes all the organisms i.e. community in a given area interacting with the physical environment so that flow of energy leads to clearly defined trophic structure, biotic diversity and material cycles i.e. exchange of materials between living and non-living within the system.

Every ecosystem has two types of components namely biotic components and abiotic components. Biotic components refer to all living organisms while abiotic components refer to non-living things. These biotic and abiotic materials maintain the equilibrium in the environment. In the present article, ecosystem, its types and structural components and ecosystem services providing to the society and environment have been discussed in some length.

Organization and dynamics of ecosystem

Ecosystem diversity refers to the variety of ecosystems in a given place. It is the variation of ecosystems found in a region or the variation in ecosystems over the whole planet and includes the variation in both terrestrial and aquatic ecosystems, such as deserts, forests, grasslands, wetlands, and ocean. It is the largest scale of biodiversity and within each ecosystem there is a great deal of both species and genetic diversity.

Ecosystem diversity is, thus, a term that incorporates both habitat and community diversity. A habitat is the environment in which an organism or species lives and includes the physical characteristics (e.g. climate or the availability of suitable food and shelter) that make it especially well suited to meet the life cycle needs of that species. A community consists of the assemblage of population of plants and animals that occupy an area and their interactions with each other and their environment. An ecosystem is a unique combination of plant, animal and microorganism communities and their non-living physical characteristics interacting as a functional unit.

Ecosystems are organized from smallest to largest: organism, population, community and ecosystem. An organism is a simple living thing and can be an animal, plant, bacteria etc. A population is a group of organisms belonging to the same species that live in the same area and interact with one another. A community is all the populations of different species that live in the same area and interact with one another. An ecosystem is made of the biotic and abiotic factors in an area. Therefore a community is the collection of multiple populations living in the same place at the same time. Communities just involve biotic and living factors. A community and its abiotic or non-living factorsare called the ecosystem. Ecosystems are dynamic. Their composition and structure may change over time especially when a disturbance occurs. Volcanic eruption is a natural disturbance that can create a new land that is open for colonization. The first species to colonize in a barren land are lichens and their biological activities will alter the condition of the environment. This will make it less harsh and more habitable for new species. The progressive replacement of one dominant type of species or community by another is called succession. The succession will go on until a climax state is established meaning the ecosystem has achieved stability and no further succession will occur unless another disturbance disrupts the ecological balance. An ecosystem is larger than a community because it includes environmental factors (abiotic components). The ecosystem is a broader level than a community; moreover, ecosystem does not change with the environmental factors though it is transformed into another form; on the other hand, community changes with the environmental factors in a particular geographical area. Example of ecosystem includes forest, grassland, desert; ponds, estuaries etc. and community include the collection of plants, animals, microorganisms etc. in a particular ecosystem.

Types of ecosystem

There are two types of ecosystem: i) Terrestrial ecosystem and ii) Aquatic ecosystem. Terrestrial ecosystems are land based having sub-types such as a) forest ecosystem, b) grassland ecosystem, c) tundra ecosystem and d) desert ecosystem. In forest ecosystem, different plants, animals and microorganisms live in coordination with the non-living components interacting with each other. It is a large and complex ecosystem typically associated with land masses covered in trees that form the canopy. It is defined by all the collective living inhabitants of the forest ecosystem that co-exist together in symbiosis to create unique ecology. Forests cover 30 per cent of Earth's surface and are home to 80 per cent of the world's terrestrial biodiversity. Forests are found on all continents except Antarctica. It may be classified according to the climatic conditions such as tropical, temperate or boreal.

Tropical forest ecosystem – Tropical forests are found in latitude 23.5^0N and 23.5^0 i.e. between Tropic of Cancer and the Tropic of Capricorn. Heavy rainfall leads to poor quality of soil due to leaching of soil nutrients. The vegetation mostly includes broad leaved trees with dense canopy restricting the sun light to touch the forest floor. It is a home for millions of animalsincluding birds, mammals, amphibians, reptiles etc. The tropical forest ecosystem is again divided into different categories and types such as i) evergreen forest, ii) seasonal forest, iii) dry forest, iv) montane forest, v) sub-tropical forest and vi) tropical and sub-tropical coniferous forest. Tropical forests play a critical role with respect to global carbon pools and fluxes as these forests store about half of the world's biomass (Brown and Lugo 1982) and 20 per cent of the global soil carbon pool (Jabbaby and Jackson 2000). However, the high diversity of decomposers, such as bacteria and fungi accelerates the decomposition process of litters and fresh organic matter enough that the nutrients released by decomposition are taken up quickly by the plants, instead of being stored in the soil. The tropical rainforest biome has four main characteristics: very high annual rainfall, high average temperature, nutrient poor soil and high level of biodiversity and dense canopies of vegetation the top layer of which contains giant trees of nearly 75m high.

Temperate forest ecosystem – Temperate forest is found between the tropical and boreal regions located in the temperate zone and is the second largest biome in the Earth. This ecosystem is found most extensively throughout the Northern Hemisphere and less extensively in the Southern Hemisphere. In temperate areas, forest consists of deciduous trees, evergreen trees or a combination. It receives less rainfall compared to tropical forest ecosystem. Unlike tropical forests, temperate forests experience with variation in temperature. In winter, temperature comes down below freezing point and in summer temperature becomes high with a high level of humidity. The soil is rich in organic matter and nutrients allowing a huge variety of vegetation to grow. Temperate deciduous forests have a great variety of plant species. Most have three levels of plants. Lichens, moss, ferns, wildflowers etc. can be found on the forest floor. Shrubs fill in the middle level and hardwood trees like maple, oak, birch, magnolia, sweet gum and beach make up the third level. Itprovides natural habitat to many animals like red fox, wood pecker, cardinals, hawks, squirrels deer, black bears etc.

Boreal forest ecosystem – Boreal forests lie between temperate forest zones and the Arctic and consist almost entirely of coniferous or evergreen trees. The main characteristic of the boreal forest is that it experiences short summer and very long winter seasons. It receives approximately 35-60 cm precipitation every year. The trees are the ever green type such as pine, fir, spruce, larch etc. having dense canopy that hardly allows the sun light to reach the forest surface. The animals lived in boreal forests are elk, caribou, moose, rabbits, lynxes, deer etc. Insects are prolific in boreal summer and many birds including waterfowl migrate to boreal forests to feed on them.

A grassland ecosystem is a dry area of land dominated by grasses. Grassland ecosystems are typically found in tropical and temperate regions. It is the collection of plants, animals and microorganisms that live within environment where grasses are the primary form of vegetation. It is the true kingdom of animals. The key characteristics of grassland ecosystem are i) vegetation structure dominated by grass, ii) limited annual rainfall and semi-arid climate, iii) most common at mid-latitude and near the interiors of the continents, iv) frequent fire due to semi-arid climate and flash lighting, v) the animals found here are grazing animals, vi) the common plant species include buffalo grass, asters, cone flowers, clover etc., vii) grasslands are often exploited for agricultural use.

The grassland ecosystem is divided into i) temperate grassland, ii) tropical grassland and iii) steppe grassland. Grasslands provide vital ecosystem services such as water and climate regulation that support agriculture, biogeochemical cycling, and carbon storage, cultural and recreational services.

Tundra ecosystems are treeless regions found in Arctic and on the tops of mountains where the climate is cold and windy and rainfall is very less. Lichens and small flowers may become visible during brief spring and summer when snows melt. Animals found in the tundra include the musk ox, the Arctic hare, the polar bear, the Arctic fox and the Arctic wolf. Tundra means treeless, therefore most of the plants are low growing plants including Arctic moss, Arctic willow, Caribou moss, cotton grass, lichens etc. Arctic tundra, Antarctic tundra and Alpine tundra are three different types of tundra. Arctic tundra is located within Arctic circle, Alpine tundra is found above the tree level in high mountain ranges. The Antarctic tundra is situated in South Pole. The oil drilling and oil exploration, mining etc. that is occurring in tundra is threatening the ecological balance of this unique biome. The tundra food web would begin with the various plant species (dry shrubs and mosses, grasses and lichens) followed by the primary consumers (herbivores) such as caribou, hares, oxen and lemmings. The tundra has few nutrients in the soil to support plants. It plays a large role in the temperature regulation of the planet. As warm air rises from the tropical zone it is cooled in the tundra causing it to sink back to the equator. This causes weather and air currents.

Desert ecosystem is the driest ecosystem of the Earth and this is the reason it have less vegetation and less diversity of life. It is one of the parts of terrestrial ecosystem. Aridity is the common characteristic of the entire desert on the Earth. Desert ecosystems experience extreme temperature. The days are very hot andnight extreme cold. Velocity of wind is very high. Due to very low rainfall there is shortage of water. The soil is dry, rocky, thin, and sandy and lack of organic matter and nutrients as a result the survival of vegetation is very hard. However, the vegetation found mostly includes bushes, acacia, cacti (Cactus) and dead trees. Desert animals include insects, reptiles and birds.

Aquatic ecosystems are located in the aquatic environment and covers about 70 per cent of the Earth. There are two types of aquatic ecosystems: i) marine ecosystem and ii) fresh water ecosystem. Marine ecosystem is the largest and exists in water having high salt content. These include the open oceans, the deep-sea ocean and coastal marine ecosystems each of which has different physical and biological characteristics and biotic factors include plants, animals and microbes and abiotic factors are sun light, oxygen and nutrients dissolved in water, depth and temperature (Alexander 1999).

Fresh water ecosystems include lakes, ponds, rivers, streams, bogs and wet lands. Fresh water ecosystem differs from marine ecosystem which have large salt content (Vaccari 2005). These two ecosystems can be classified on the basis of temperature, light penetration, nutrient and vegetation. There are three basic types of fresh water ecosystem: Lentic (slow moving water i.e. ponds, lakes, etc.) and Lotic (faster moving water i.e. streams and river) and west lands (areas where soil is saturated or inundated for at least part of the time). Fresh water ecosystem contains 40 per cent of the world's fish species (Daily 1997). The plants, animals, microbes, rocks, soil, sun light and water found in and around this valuable resource are all parts of these ecosystems (Carpenter *et al.* 2011).

Structural components of ecosystem

As stated previously the ecosystem is largely divided into two functional components: the abiotic and biotic. The abiotic components refer to the physical environment or the non-living factors such as materials and the energy. The materials are soil, atmosphere, solar radiation, water, minerals, nutrients, wind, gases, altitude salts etc. They also include some organic matter such as amino acids and other products of decay of living things. The energy is in the form of sun light, heat and stored energy in chemical bonds. Without the abiotic components, organisms can not live or survive. Biotic components refer to all life in an ecosystem. Based on nutrition, biotic components can be categorized into autotrophs, heterotrophs and saprotrophs.

Every ecosystem has four structural components: i) Producers, ii) Consumers, iii) Decomposers and iv) abiotic substances or components. Plants and lichens are the pioneering producers. Trees, shrubs, vines, grasses, mosses are the primary producers in temperate and tropical climates. In the Arctic regions where plants are not well equipped to survive, lichen – symbiotic organisms made up of photosynthesizing algae or cyanobacteria and fungus are the primary producers. Algae, a broad grouping aquatic plant or plant like organism that contains chlorophyll, are the basis of all aquatic life webs. In any ecosystem, producers are of the base of the entire food web. Producers or autotrophic organisms utilize sun light as their energy source and simple inorganic materials like water, CO_2 and saltsto produce their own foods. Producers are largely photosynthetic plants and their kind varies with the kind of ecosystem. In the dense forest, plants, bacteria, algae and phytoplankton are the foundation ofan ecosystem's food chains. The many parts of the producer can feed several kinds of organisms such as plants make seeds, leaves, roots etc. to feed different animals.

Consumers belonging within the food chains of the ecosystem are unable to make their own food and instead rely on the consumption and digestion of producers or other consumers or both to survive and are therefore called heterotrophs. All heterotrophs are consumers and are classified by the type of organisms they eat and their place in the ecosystem. The food they eat is then digested i.e. broken down to simple substances which are metabolized and the waste products of their metabolism are released in the environment providing the food of the secondary consumers or producers or tertiary consumers. Consumers examples include mammals, birds, fish, reptiles, amphibians, insects, fungi and microscopic organisms such as protozoa and some types of bacteria.

Decomposers are a type of consumers and also called saprophytes. They are also the living components chiefly the bacteria, fungi, molds and earthworms. They derive their food directly or indirectly from producers or green plants. The waste products after metabolism are released for producers to use. The vast majority of decomposers are animals. Decomposition is an important process in the ecosystem because it allows organic materials to be recycled and without the activity of the decomposer the entire cycle of minerals will be blocked.

Thus it is seen that the whole of the system from producer to decomposer is a cyclic process. Primary producers use energy from Sun to produce their own food in the form of glucose and the primary producers are eaten by primary consumers who are in turn eaten by secondary consumers and so on so that energy flows from one trophic level or level of food chain to the next. The process ends after the death or decomposition of the consumers thereby becoming the food of the producers starting the cycle again.

Ecosystem services

Ecosystem function is the capacity of natural process and component to provide goods and services that satisfy human needs, either directly or indirectly (de Groot *et al.* 2010). Ecosystem service is any positive benefit that ecosystem provides to society. The services make human life possible by providing nutritious food and clean air and water, regulating diseases, supporting pollination of crops and soil formation and providing recreational, cultural and spiritual benefits. Healthy ecosystems provide raw materials and resources for medicines and other purposes. They are at the foundation of all civilization and sustain our economics. Ecosystem services are grouped into four broad categories: i) provisioning, ii) regulating, iii) supporting and iv) cultural.

Provisioning services- A provisioning service is the benefit to people that can be extracted from nature e.g. food, fruits, vegetables, trees, wood, fish, livestock etc. These are all the direct products of the ecosystem. Along with food and others, provisioning services also include drinking water, timber, wood fuel, natural gas, oil, plants for making cloths, medicines etc.

Regulating services – The variety and variability of animals, plants and microorganisms at the genetic, species and ecosystem levels is necessary to sustains key functions of the ecosystems, its structure and processes. Plants clean air and filter water, bacteria decompose wastes, bees pollinate flowers and tree roots hold soil in place to prevent erosion. Regulating services also include pollination, decomposition, erosion and food control and carbon storage and climate regulation. Pollination is the art of transferring pollen grains from the male anther of a flower to female stigma. The goal of every living organism including plants is to create offspring for the next generation. A pollinator is an animal that moves pollen from the male anther of a flower to the female stigma of a flower. Birds, bats, butterflies, moth, flies, small mammals and most important, bees are pollinators. Insects and other animal pollinators are vital to the production of healthy crops for food, fibers, edible oils, medicines and other products. There are approximately 200,000 different species of animals around the world that act as pollinators (FAO 2018).

Supporting services – These services are necessary for the production of all other ecosystem services and include biomass production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling and provisioning of habitat, pollination and maintains order in nature. Without supporting services, all other services would not exist. The Millennium Ecosystem Assessment Report (2005) defined ecosystem as the benefits people obtain from ecosystems and distinguishes four categories of ecosystem services where the so called supportingservices are regarded as the basis for the services of the other three categories. Nutrient cycling is one of the important supporting services of the ecosystem. There are 17 essential elements needed by plants and animals for their existence on Earth. Out of 17, some are classed as macro-nutrients because these are required by plants and animals in fairly large quantity, the remaining although required in small amount are very much essential for their development. The most important parts of the nutrient cycle relate to the exchange of nutrients among three pools: that in the above ground plants and animals, that within soil organic matter and that in the inorganic forms in the soil consisting inorganic ions derived from the weathering of rocks and minerals.

Cultural services – A cultural service is a non-material benefit that contributes to the development and cultural advancement of people, including how ecosystems play a role in local, national and global cultures;

the building of knowledge and the spreading of ideas; inspiration of aesthetic and engineering; cultural identity and spiritual well-being. Healthy clean and biodiverse fresh water ecosystem attract a range of different user groups. Walkers and sightseers may use bank side paths, trails and viewpoints drawn by a landscape's aesthetic appeal, histories and iconic species often in national parks and protected areas.

Thus, healthy ecosystems clean our water, purify our air, maintain our soil, regulate the climate and diseases, recycle nutrients and provide food and raw material for medicines, support the pollination of crops and soil formation. They are at the foundation of all civilization and sustain our economies. Theyalso provide recreational, cultural and spiritual benefits.

Conclusion

Ecosystem services are the multitude and varied benefits that nature provides to the society. Ecosystem services make human life possible by providing nutritious food and clean water, regulating diseases and climate, supporting the pollination of crops, soil formation and providing recreational, cultural and spiritual benefits. Many key ecosystem services are provided by biodiversity such as nutrient cycling, water cycling, carbon sequestration, pest regulation and pollination and sustain agricultural productivity. Biodiversity as with ecosystem services must be protected and sustainably managed for the betterment of the world.

References

Alexander, D.E. (1999). *Encyclopedia of Environmental Science*, Springer

Brown, S. and A.E. Lugo (1982). The storage and production of organic matter in tropical forests and their role in the global carbon cycle. ***Biotropica*,**14: 161-187

Carpenter, S.R., E.H. Stanley and M.J. Vander Zanden (2011). State of the World's fresh water ecosystem: Physical, chemical and biological changes. *Annual Review of Environment and Resources*,**36:** 75-99

Chapin, F. and Ill, Stuart (20110. The ecosystem concept. In: (P.A. Mattson *et.al.*eds.) *Principles of Terrestrial Ecosystem Ecology*, (2nd. edn.), New York, Springer

Daily, G.C. (1997). *Nature's Services*, Island Press, Washington D.C.

de Groot, R.S., R. Alkemade, L. Barat *et al.* (2010). Challenge in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, **7**(3): 260-272

FAO (2018). The Pollination of Cultivated Plants, vol. 1. Food and Agricultural Organization of the United Nations, Rome, Italy

Jobbagy, E.G. and R.B. Jackson (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecol. Appl.*,**10:** 423-436

Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-being: Synthesis, Island Press, Washington D.C.

Odum, E.P. (1971). *Fundamental of Ecology* (3rd. edn.), New York, Saundars

Vaccari, D.A. (2005). *Environmental Biology for Engineers and Scientists*, Wiley International.

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