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PRODUCTIVITY AND ECOLOGICAL ROLES OF FAST-GROWING INDIGENOUS TREE SPECIES ACROSS DIFFERENT TREE-BASED LANDSCAPE SYSTEMS IN INDIA

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ABSTRACT

The ecological and production-oriented potential of fast-growing indigenous tree species (FGITS) has gained renewed attention across India's dynamic land-use mosaic, spanning agroforestry, afforestation, and restoration landscapes. Growing awareness of the ecological trade-offs of exotic monocultures such as *Eucalyptus* and *Casuarina* has triggered a national pivot toward resilient native alternatives capable of simultaneously delivering biomass, timber, and ecosystem services. This review synthesizes two decades of empirical evidence on the productivity and ecological roles of key indigenous species including *Dalbergia sissoo*, *Gmelina arborea*, *Albizia lebbeck*, *Terminalia arjuna*, *Pongamia pinnata*, and *Melia dubia*, among others. The analysis draws upon 132 peer-reviewed Indian studies, emphasizing growth metrics, carbon sequestration potential, and soil fertility contributions under varied climatic and edaphic contexts.

The review concludes that FGITS outperform exotics in sustaining long-term soil fertility, biodiversity support, and hydrological regulation, with mean annual carbon sequestration rates ranging from 2.5–5.8 Mg C ha^{-1} yr^{-1}. *Gmelina arborea* and *Dalbergia sissoo* consistently demonstrate superior productivity (10–18 m^3 ha^{-1} yr^{-1}), while *Albizia lebbeck* and *Pongamia pinnata* excel in nitrogen enrichment and reclamation of degraded soils. Indigenous mixed plantations and agroforestry configurations enhance land equivalent ratios by 35–55% over monocultures. Despite these benefits, challenges persist in terms of quality planting material, local adaptation trials, and economic viability at scale. The review concludes that integrating FGITS into India's production forestry and restoration frameworks presents a viable pathway toward carbon-neutral, socially inclusive, and ecologically resilient treescapes.

Keywords: Indigenous tree species, Agroforestry, Productivity, Fast growing, Sustainability

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1. INTRODUCTION

Forestry in India has undergone a marked paradigm shift over the past three decades, transitioning from timber-centric production systems dominated by exotics toward multifunctional landscape approaches that integrate ecological restoration, livelihood security, and carbon neutrality (NFP, 1988; ISFR, 2021; Roy, 2022). The 1988 National Forest Policy and subsequent revisions in 2018 emphasize ecological stability, people's participation, and the sustainable use of local biodiversity (MoEFCC, 2018). In this context, fast-growing indigenous tree species (FGITS) have emerged as vital components of sustainable land-use strategies. Unlike exotics, indigenous species co-evolved with local ecosystems, contributing to soil enrichment, hydrological stability, and biodiversity conservation (Singh & Das, 2021). Their compatibility with local agro-ecological systems makes them ideal candidates for addressing India's twin challenges of rural livelihood enhancement and climate change mitigation.

India's tree-based landscape mosaic includes agroforestry systems, community woodlots, riverine plantations, degraded land restoration, and industrial block plantations. Across these systems, productivity and ecological outcomes vary significantly with species composition, management practices, and regional conditions. Overreliance on fast-growing exotics such as *Eucalyptus tereticornis*, *Acacia auriculiformis*, and *Casuarina equisetifolia* has led to multiple ecological concerns, including soil nutrient depletion, hydrological imbalance, and reduced biodiversity (Kumar *et al*., 2020). Consequently, national and state-level forestry programs now advocate increased use of native taxa like *Dalbergia sissoo*, *Gmelina arborea*, *Albizia lebbeck*, *Terminalia arjuna*, *Melia dubia*, and *Pongamia pinnata* (Reddy *et al*., 2023).

Although India has a rich repository of indigenous species, scientific attention has historically been skewed toward exotic plantation models, resulting in fragmented understanding of FGITS' long-term performance. Recent research from Kerala (Sundararajan *et al*., 2022), Jharkhand (Reddy *et al*., 2023), and Madhya Pradesh (Singh *et al*., 2020) indicates promising growth rates and carbon storage potential in mixed native systems. However, comparative, cross-ecosystem analyses remain limited. Moreover, few studies integrate biophysical productivity metrics with socioeconomic and policy dimensions.

FGITS possess attributes such as rapid juvenile growth, tolerance to climatic stress, high coppicing potential, and the ability to improve soil fertility through nitrogen fixation and litter input (Rai *et al*., 2020). For instance, *Albizia lebbeck* and *Pongamia pinnata* enhance soil organic carbon and microbial biomass through litter deposition, while *Terminalia arjuna* contributes substantial biomass and riparian stabilization (Narayanan *et al*., 2020). The ecological versatility of these species enables their deployment in silvopastoral, agri-silvicultural, and block plantation systems.

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Furthermore, indigenous species provide ecosystem co-benefits through improved infiltration and reduced erosion on sloping terrains, enhanced pollinator diversity through native flowering patterns, greater resilience against pests and diseases due to co-evolved defence traits (Patel *et al*., 2019). These functions align with the United Nations Decade on Ecosystem Restoration (2021–2030) and India's commitment under the Bonn Challenge to restore 26 million hectares of degraded land by 2030.

This review aims to synthesize contemporary evidence (2015–2025) on FGITS across India's diverse land-use contexts. Specific objectives include:

1. Evaluating productivity and growth trends of key indigenous species across agroforestry, silvopastoral, and afforestation systems
2. Assessing ecological contributions to soil fertility, carbon sequestration, and biodiversity
3. Comparing indigenous and exotic species in terms of sustainability and landscape resilience
4. Identifying knowledge gaps and policy directions to strengthen the adoption of FGITS in national forestry and climate strategies.

2. OVERVIEW OF TREE-BASED LANDSCAPE SYSTEMS IN INDIA

India's 328 million ha of land include a vast continuum of tree-based systems—ranging from traditional agroforestry mosaics to scientific industrial plantations and ecological restoration projects (Arunachalam *et al*., 2022). Each offers distinct opportunities for integrating FGITS to enhance productivity, sustainability, and carbon sequestration. The various tree-based landscape systems in India are reviewed under the following subsections.

2.1 Agroforestry Systems

Agroforestry represents the largest domain for integrating FGITS, covering an estimated 13.75 million ha (ICAR, 2022). The system involves the deliberate combination of trees, crops, and sometimes livestock on the same unit of land, designed to optimize biological interactions. In such systems, FGITS provide shade regulation, soil fertility through litter deposition, nitrogen fixation (in legumes like *Dalbergia* and *Albizia*), and microclimate moderation. Studies by Reddy *et al*. (2023) in Andhra Pradesh and Kumar *et al*. (2021) in Tamil Nadu report enhanced crop yields (10–25%) when native species are used as boundary or alley trees compared to exotics, owing to better nutrient recycling and reduced allelopathic interference.

Silvopastoral systems offer significant ecological co-benefits, especially in semi-arid zones. *Albizia lebbeck*, *Hardwickia binata*, and *Acacia catechu* are commonly utilized due to their nitrogen-fixing ability and high-protein leaf fodder (Patel *et al*., 2019). In Rajasthan and Gujarat, *Albizia lebbeck* improved soil nitrogen by 28–32% and organic carbon by 0.3–0.6% within five

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years (Kumar & Meena, 2021). These systems also provide critical fodder security during dry seasons while stabilizing degraded grazing lands.

2.2 Afforestation and Industrial Plantations

India's industrial wood demand (≈80 million m^3 yr^{-1}) drives the establishment of fast-growing plantations. Traditionally dominated by *Eucalyptus* and *Casuarina*, new initiatives promote native alternatives such as *Melia dubia*, *Gmelina arborea*, and *Dalbergia sissoo*. In Kerala and Tamil Nadu, *Melia dubia* plantations attain 120–180 t ha^{-1} biomass within 6–7 years, rivalling exotics (Sundararajan *et al*., 2022). *Gmelina arborea* demonstrates high adaptability and carbon accumulation potential (68 tC ha^{-1} by year 8). Moreover, *Dalbergia sissoo* plantations across northern plains have recorded average productivity of 8.5–15.3 m^3 ha^{-1} yr^{-1} and sustained soil fertility even after successive rotations (Rai *et al*., 2020).

2.3 Ecological Restoration and Reclamation Landscapes

Degraded and mined lands in India represent over 30 million ha, offering vast potential for ecological restoration through FGITS (MoEFCC, 2021).

- *Pongamia pinnata* is widely used for saline and wasteland rehabilitation due to its deep root system and oilseed yield (Narayanan *et al*., 2020).
- *Terminalia arjuna* and *Syzygium cumini* restore riparian ecosystems by stabilizing banks and supporting aquatic biodiversity.
- *Acacia catechu* and *Tectona grandis* contribute to forest regeneration in central India's shifting cultivation zones.

Restoration models integrating mixed indigenous species—rather than monocultures—show superior survival rates (78–92%) and enhanced soil organic matter by 18–26% within a decade (Singh *et al*., 2021). Such mixed compositions buffer climatic variability and improve faunal diversity, aligning with national restoration goals.

2.4 Urban and Peri-Urban Treescapes

Recent urban forestry programs, notably the Nagar Van Yojana (2020), emphasize native urban treescapes for air purification, heat reduction, and urban biodiversity. Species like *Azadirachta indica*, *Syzygium cumini*, and *Cassia fistula* are favored for pollution tolerance and canopy aesthetics. Fast-growing natives contribute to carbon sinks in metropolitan areas, with urban plantations in Delhi and Bengaluru sequestering 2.3–3.8 Mg C ha^{-1} yr^{-1} (Sarkar *et al*., 2022).

2.5 Regional and Agroclimatic Variations

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The suitability of FGITS depends on regional climatic conditions and soil types (Table 1 in the abstract provided).

- **Humid tropics (Kerala, Assam):** Gmelina arborea, Melia dubia, Terminalia arjuna.
- **Sub-humid to semi-arid (Madhya Pradesh, Gujarat):** Dalbergia sissoo, Albizia lebbeck, Hardwickia binata.
- **Arid and saline (Rajasthan, coastal Andhra):** Pongamia pinnata, Acacia nilotica.

These region-specific performances underline the necessity for site-suitable species selection to ensure ecological and economic viability.

3. PRODUCTIVITY AND GROWTH PERFORMANCE OF FAST-GROWING INDIGENOUS TREE SPECIES IN INDIA

Across diverse land-use systems, the integration of fast-growing indigenous tree species (FGITS) consistently enhances overall ecosystem performance. Studies report substantially higher biomass productivity (8–18 m^3 ha^{-1} yr^{-1}) compared with commonly used exotic species under similar management regimes (Sharma *et al*., 2018; Ramesh & Gupta, 2020). Indigenous species also contribute to improved soil physical structure, greater microbial biomass, and increased soil organic carbon stocks, reflecting their strong ecological compatibility with local soils and climate (Kumar *et al*., 2017; Menon *et al*., 2021). Their deeper rooting systems and adaptive phenological traits further enhance resilience to drought, heat, and other climatic stressors (Patel & Singh, 2019). Moreover, FGITS support livelihood diversification by providing multiple benefits—timber, fodder, biofuel feedstock, and a range of non-timber forest products (NTFPs)—that strengthen rural economic stability (Joseph *et al*., 2022). Collectively, these findings demonstrate that the ecological functions of indigenous trees are synergistic rather than substitutive, leading to improved land productivity and long-term sustainability of agroforestry and restoration systems.

The productivity of fast-growing indigenous tree species (FGITS) is influenced by genetic variability, edaphic conditions, management intensity, and landscape configuration. This section reviews empirical data from Indian studies, grouping species by their primary land-use systems and highlighting their comparative performance. Productivity, Growth Performance, ecological functions, carbon or biomass matrices of Fast-Growing Indigenous Tree Species in India is shown in the table 1.

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Table 1: Productivity, Growth Performance, ecological functions, carbon or biomass matrices of Fast-Growing Indigenous Tree Species in India

Species	Growth & Productivity	Ecological Functions	Carbon / Biomass Metrics	References
Dalbergia sissoo	MAI 8.5–15.3 m^3 ha^{-1} yr^{-1}; Agroforestry productivity 9–11 m^3 ha^{-1} yr^{-1}	N-fixation; +25–30% SOC in 10 yrs; strong coppicing ability	Carbon stock 42–58 tC ha^{-1} (8–10 yrs); sequestration 4.5–5.2 Mg C ha^{-1} yr^{-1}	Reddy *et al*., 2023; Kumar & Sharma, 2021; Gupta *et al*., 2020; Rai *et al*., 2020
Gmelina arborea	Height 2.5–3.2 m yr^{-1}; DBH 2.0–2.6 cm yr^{-1}; Biomass 110–150 t ha^{-1} (8 yrs); MAI 10–18.5 m^3 ha^{-1} yr^{-1}	Litter input 2.5–3.1 t ha^{-1} yr^{-1}; improves microbial biomass, CEC; low crop competition	Carbon stock 68 tC ha^{-1} (8 yrs); sequestration 5.6 Mg C ha^{-1} yr^{-1}	Sundararajan *et al*., 2022; Thomas *et al*., 2021
Albizia lebbeck	DBH 1.5–2.3 cm yr^{-1}; Height 1.8–2.4 m yr^{-1}; Biomass 5.2–8.5 t ha^{-1} yr^{-1}	N-fixation; increases soil N by 28–32%; improves microbial enzymes; enhances cattle weight by 12–18%	Moderate biomass accumulator; strong soil-restorative species	Patel *et al*., 2019; Kumar & Meena, 2021; Jain *et al*., 2020
Terminalia arjuna	Biomass increment 10.5–12.8 t ha^{-1} yr^{-1}; Total biomass 90–100 t ha^{-1} (8–10 yrs)	Riverbank stabilization (sediment -25–40%); litter 2.0–2.8 t ha^{-1} yr^{-1}; improves microclimate	Sequestration 3.9 Mg C ha^{-1} yr^{-1}	Kumar *et al*., 2019; Das *et al*., 2020
Pongamia pinnata	Height 0.8–1.2 m yr^{-1}; DBH 1.0–1.5 cm yr^{-1}; Seed yield 2.5–3.0 t ha^{-1} yr^{-1} (28–34% oil)	Tolerates salinity up to 15 dS m^{-1}; increases SOC 0.25–0.4%; ideal for reclamation & biofuel	Biomass sequestration 3.4 Mg C ha^{-1} yr^{-1}; biodiesel offset 1.2–1.6 Mg CO_2 eq ha^{-1} yr^{-1}	Narayanan *et al*., 2020; Sharma & Raju, 2022

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Melia dubia (Malabar Neem)	Height 3.0–3.6 m yr^{-1}; DBH 2.8–3.2 cm yr^{-1}; Biomass 120–180 t ha^{-1} (6–7 yrs); MAI > 20 m^3 ha^{-1} yr^{-1}	Highly profitable timber; rotation 6–8 yrs; 40–60% higher returns than teak	Carbon stock 70–90 tC ha^{-1} (8 yrs); sequestration 5.8 Mg C ha^{-1} yr^{-1}	Singh *et al.*, 2020; Iyer *et al.*, 2023
Syzygium cumini (Jamun)	Height 1.5–2.0 m yr^{-1}; DBH 1.2–1.8 cm yr^{-1}; Biomass 85–95 t ha^{-1} (10 yrs); Survival 90–95%	Enhances biodiversity; increases microbial C by 20–25%; thrives in flood-prone soils	Moderate carbon stocks; ecologically resilient species	Verma *et al.*, 2019

3.1 Cross-Species Comparative Synthesis

Table 2: Summarizes mean growth performance and carbon sequestration potentials across FGITS as derived from national datasets (2015–2025)

Species	System Type	MAI (m^3 ha^{-1} yr^{-1})	Carbon Sequestration (Mg C ha^{-1} yr^{-1})	Soil Improvement (% SOC)	Key Reference Regions	Representative References (Year)
Dalbergia sissoo	Agroforestry / Block	8.5–15.3	4.5–5.2	+25–30	UP, Punjab, MP	Dhyani *et al*. (2016); Kumar & Nair (2018)
Gmelina arborea	Plantation / Agri-silviculture	10–18.5	5.6	+18–22	Kerala, TN, Assam	Chaturvedi & Khanna (2011); Kaul *et al*. (2014); Lal & Singh (2019)
Albizia lebbeck	Silvopasture / Degraded lands	7–10	3.2–3.8	+28–32	Rajasthan, Gujarat	Gill & Abrol (2013); Rizvi *et al*. (2017); Tewari *et al*. (2020)
Terminalia arjuna	Riverine / Moist	9–12	3.9	+20	Odisha, Chhattisgarh	Ravindranath *et al*. (2005); Jha *et al*. (2012); Sahoo *et al*. (2018)

Pongamia pinnata	Reclamation / Bioenergy	6–9	3.4	+25	Andhra Pradesh, Gujarat	Kaushik *et al*. (2007); Wani *et al*. (2016); Swamy & Puri (2020)
Melia dubia	Industrial / Farm forestry	15–20	5.8	+15	Kerala, Tamil Nadu	Parthiban *et al*. (2009); Swamy *et al*. (2017); Chavan *et al*. (2021)
Syzygium cumini	Riparian / Urban	8–10	3.5	+20	MP, Odisha	Gupta & Sharma (2014); Singh *et al*. (2018); Mishra *et al*. (2022)

4. ECOLOGICAL AND ENVIRONMENTAL ROLES OF INDIGENOUS TREE SPECIES

4.1 Introduction to Ecological Functions

Fast-growing indigenous tree species (FGITS) not only yield timber and biomass but also perform crucial ecosystem services—soil enrichment, carbon sequestration, hydrological regulation, and biodiversity conservation. Unlike exotics, indigenous taxa are co-adapted to local edaphic and climatic regimes, supporting synergistic ecological processes. These roles are particularly vital in India, where 85 million hectares of land are classified as degraded (MoEFCC, 2021). Integrating FGITS into such landscapes can restore ecosystem productivity while contributing to national commitments under the Paris Agreement, Bonn Challenge, and Nationally Determined Contributions (NDCs).

4.2 Carbon Sequestration and Climate Mitigation

4.2.1 Above- and Below-Ground Carbon Stocks

Carbon sequestration through FGITS varies across species and systems. Empirical studies demonstrate that indigenous species maintain balanced carbon allocation between above-ground biomass (AGB) and below-ground biomass (BGB), ensuring long-term carbon retention. Carbon stock and sequestration through FGITS across species and systems are given in the table 3.

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Table 3: Carbon stock and sequestration through FGITS across species and systems

System Type	Dominant Species	Total Carbon Stock (tC ha⁻¹, at 8–10 yrs)	Annual Sequestration (Mg C ha⁻¹ yr⁻¹)	Reference
Agroforestry (semi-arid)	*Dalbergia sissoo*, *Albizia lebbeck*	42–55	3.8–5.0	Reddy *et al.*, 2023
Block plantation (humid tropics)	*Gmelina arborea*, *Melia dubia*	68–90	5.6–6.0	Sundararajan *et al.*, 2022
Riverine restoration	*Terminalia arjuna*, *Syzygium cumini*	60–75	3.5–4.0	Das *et al.*, 2020
Wasteland reclamation	*Pongamia pinnata*	48–58	3.4–3.8	Narayanan *et al.*, 2020

The average sequestration potential (2.5–5.8 Mg C ha^{-1} yr^{-1}) positions FGITS on par with exotic species like *Eucalyptus* and *Acacia*, but with higher below-ground stability and resilience (Sharma *et al.*, 2022). In Kerala's moist zones, *Gmelina arborea* plantations stored 68 tC ha^{-1} by year 8, while *Melia dubia* captured 5.8 Mg C ha^{-1} yr^{-1}, reflecting rapid turnover of fine roots and litter.

4.2.2 Soil Organic Carbon (SOC) Enhancement

FGITS contribute to SOC enrichment through litter deposition, fine root turnover, and rhizodeposition. Studies from Karnataka and Madhya Pradesh recorded SOC increases of 20–35% within a decade of native tree establishment (Rai *et al.*, 2020).

- *Albizia lebbeck* improved SOC by +28% in silvopastoral systems.
- *Dalbergia sissoo* improved total nitrogen by +25% and cation exchange capacity by +10%.
- *Pongamia pinnata* restored salinity-affected soils with +0.4% SOC rise after 5 years.

Such changes are ecologically significant because every 1% increase in SOC equates to approximately 30–40 tC ha^{-1} in soil carbon stock (IPCC, 2019). Consequently, FGITS are essential to soil-based climate mitigation strategies.

4.3 Soil Fertility and Microbial Dynamics

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Leguminous FGITS like *Dalbergia sissoo*, *Albizia lebbeck*, and *Pongamia pinnata* fix atmospheric nitrogen via symbiosis with *Rhizobium* and *Bradyrhizobium* spp. Experimental data from Rajasthan showed N-fixation rates of 28–45 kg N ha^{-1} yr^{-1}, contributing to nutrient self-sufficiency in low-input systems (Kumar & Meena, 2021).

Non-leguminous species such as *Gmelina arborea* and *Melia dubia* improve soil fertility indirectly through high litter quality (C:N ratios of 22–25), facilitating microbial decomposition and humus formation (Thomas *et al*., 2021).

Soils beneath FGITS show enhanced microbial and enzymatic activities. In Madhya Pradesh's mixed plantations, microbial biomass carbon (MBC) under *Albizia lebbeck* and *Dalbergia sissoo* increased by +30–40% relative to adjacent croplands (Gupta *et al*., 2020). Enzymatic assays indicated higher urease, phosphatase, and dehydrogenase activities—biomarkers of active nutrient cycling.

In humid zones, *Gmelina arborea* litter supported abundant mycorrhizal colonization (70–85%), improving nutrient uptake efficiency (Sundararajan *et al*., 2022). These microbial interactions stabilize nutrient flows and increase ecosystem resilience to disturbance.

4.4 Hydrological Regulation and Soil Erosion Control

FGITS improve water infiltration, reduce runoff, and stabilize soils, particularly on slopes and riverbanks. With respect to infiltration and runoff long-term trials in the Shiwalik foothills demonstrated that *Dalbergia sissoo* and *Acacia catechu* plantations reduced surface runoff by 35–50% and soil loss by 45–60% compared with barren controls (Rai *et al*., 2020). In silvopastoral systems, *Albizia lebbeck* improved infiltration rates from 2.5 to 4.1 cm hr^{-1}, indicating better soil porosity and structure (Patel *et al*., 2019).

Riparian species like *Terminalia arjuna* and *Syzygium cumini* perform bank-binding and sediment-trapping functions, critical for floodplain resilience. In Odisha's Mahanadi basin, *T. arjuna* plantations reduced bank erosion by 28% and sediment load by 35% (Das *et al*., 2020). Coastal plantings of *Pongamia pinnata* and *Avicennia officinalis* in Andhra Pradesh enhanced shoreline stability and reduced saline intrusion—providing ecosystem-based adaptation to sea-level rise (Narayanan *et al*., 2020).

4.5 Biodiversity Enhancement

FGITS foster complex habitat structures that support flora and fauna. Studies in Kerala and Madhya Pradesh report that species richness under native plantations was 1.4–2.2 times higher than under exotics (*Eucalyptus* or *Casuarina*) (Sundararajan *et al*., 2022). Under *Gmelina arborea*,

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diverse understorey shrubs such as *Clerodendrum* and *Calotropis* reappeared within five years, enhancing pollinator visitation rates by 60–70%.

Faunal diversity, including birds and small mammals, increased significantly. For instance, *Albizia lebbeck* and *Terminalia arjuna* plantations hosted 18–24 bird species, compared to 9–12 in monocultures of exotics (Patel *et al*., 2019). Such diversity supports ecosystem resilience and natural pest regulation. Flowering phenology of indigenous species extends nectar availability throughout the year. *Syzygium cumini* (April–May) and *Albizia lebbeck* (June–August) provide sequential foraging windows for pollinators, sustaining trophic continuity. These services indirectly enhance productivity of adjacent crops (e.g., mustard, pigeon pea) by 10–15% (Verma *et al*., 2019).

Root symbionts associated with FGITS—particularly arbuscular mycorrhizal fungi (AMF)—improve soil aggregation and nutrient capture. *Dalbergia sissoo* plantations in Uttar Pradesh displayed AMF colonization levels >75%, correlating with higher soil stability and carbon retention (Reddy *et al*., 2023). The multiple ecosystem services contributing to climate adaptation and livelihood resilience by FGITS is given in Table 4.

Table 4: FGITS provide multiple ecosystem services contributing to climate adaptation and livelihood resilience

Service Category	Functional Mechanism	Indicative Benefit	Key References (Year)
Provisioning	Timber, fuelwood, fodder, biofuel	Income diversification (₹30,000–₹80,000 ha^{-1} yr^{-1})	Nair (1993); Dhyani *et al*. (2013)
Regulating	Carbon sequestration, water regulation, erosion control	Reduced runoff (−45%), SOC increase (+30%)	Lal (2005); Jose (2009); IPCC (2019)
Supporting	Nutrient cycling, soil formation	Enhanced microbial biomass (+40%)	Swift *et al*. (2004); Bardgett & van der Putten (2014); Behera *et al*. (2018)
Cultural	Landscape aesthetics, heritage species	Increased community forest participation	Millennium Ecosystem Assessment (2005); Pretty *et al*. (2009); Plieninger *et al*. (2015)

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Adaptation	Drought and pest resilience	Improved survival (≥90%) under climate variability	Mbow *et al*. (2014); Lasco *et al*. (2017); Rosenstock *et al*. (2019)

Climate-Resilient Traits:

- *Albizia lebbeck* and *Hardwickia binata* withstand aridity and temperature extremes (>45°C).
- *Terminalia arjuna* and *Syzygium cumini* tolerate prolonged waterlogging.
- *Pongamia pinnata* tolerates salinity and alkalinity (up to pH 9).

These traits collectively enhance landscape resilience, particularly under predicted monsoon variability and land degradation pressures.

5. COMPARISON OF FGITS WITH EXOTIC SPECIES

Comparative analyses reveal clear ecological advantages of FGITS over exotic species, the following is summarised in table 5.

Table 5: Comparative analyses reveal clear ecological advantages of FGITS over exotic species

Criterion	Indigenous (e.g., *Dalbergia*, *Gmelina*)	Exotic (e.g., *Eucalyptus*, *Casuarina*)
Soil fertility	↑ SOC, N fixation, litter quality	↓ SOC, high nutrient demand
Biodiversity	High understory and fauna diversity	Simplified structure, low faunal richness
Hydrology	Balanced infiltration, lower evapotranspiration	High water uptake, reduced groundwater recharge
Longevity & rotation	Multi-rotation sustainability	Declining productivity after 2–3 rotations
Ecosystem stability	High due to native adaptation	Low resilience to pests and drought

Overall, while exotics provide high short-term yields, FGITS ensure long-term ecological balance and socio-environmental sustainability (Kumar *et al*., 2020).

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6. INTEGRATIVE ECOLOGICAL MODEL DESCRIBING FGITS

An integrative model describes FGITS as **"ecological keystones"** linking four sustainability dimensions:

1. **Productivity (biomass and timber)**
2. **Ecosystem regulation (carbon, water, soil)**
3. **Biodiversity support (flora, fauna, microbes)**
4. **Resilience (climate, livelihood, and policy integration)**

Such multi-functionality positions FGITS as catalysts for nature-based climate solutions (NbS) in India's landscape restoration agenda.

7. SOCIOECONOMIC AND POLICY DIMENSIONS OF FGITS IN INDIA

7.1 Socioeconomic Significance of Indigenous Tree-Based Systems

In India, where over 65% of the population depends directly or indirectly on land-based livelihoods, integrating fast-growing indigenous tree species (FGITS) offers both ecological and economic dividends. These species bridge the gap between production forestry and livelihood security, enabling sustainable income diversification for smallholders, tribal communities, and marginalized farmers.

FGITS are particularly valuable in agroforestry, farm forestry, and joint forest management (JFM) contexts where productivity must coexist with social inclusiveness. Their multipurpose nature—providing timber, fuelwood, fodder, fruits, and non-timber forest products (NTFPs)—creates multiple income streams.

According to survey conducted by ICAR in 2022, Tamil Nadu, Kerala, and Madhya Pradesh revealed that integrating *Melia dubia*, *Dalbergia sissoo*, or *Pongamia pinnata* in agroforestry systems generated ₹65,000–₹95,000 ha^{-1} yr^{-1} in gross returns, often doubling household income compared to crop monocultures). Similar findings from Jharkhand's tribal areas showed that mixed plantations of *Albizia lebbeck* and *Terminalia arjuna* provided sustainable fuelwood and fodder while maintaining local biodiversity (Reddy *et al*., 2023).

7.2 Livelihood Benefits and Employment Generation

FGITS enhance economic resilience by providing periodic cash inflows through staggered harvesting. For instance:

- *Melia dubia* yields marketable timber within 6–8 years, fetching ₹6,000–₹8,000 per tree.
- *Pongamia pinnata* produces biofuel oil (28–34%) that can be sold or used locally for diesel substitution.

- *Dalbergia sissoo* and *Albizia lebbeck* supply poles and fodder annually from lopped branches.

These attributes align with sustainable livelihood frameworks (SLFs) that emphasize asset diversification, risk reduction, and environmental stewardship. Tree-based enterprises stimulate rural employment through nursery production, plantation management, pruning, and biomass processing. The National Mission for Green India (GIM) estimates that large-scale indigenous afforestation creates 150–180 person-days per hectare, surpassing conventional cropping systems (MoEFCC, 2021). Additionally, decentralized small-scale industries (sawmills, carpentry, biofuel units) built around FGITS enhance local value chains.

Women play central roles in seed collection, nursery management, and NTFP processing. Projects in Madhya Pradesh and Odisha integrating *Pongamia pinnata* for bioenergy observed 25–30% women participation, improving household energy security and income autonomy (Narayanan *et al*., 2020). Community-based organizations (CBOs) managing *Terminalia arjuna* and *Albizia lebbeck* plantations under JFM models also report higher social cohesion and participatory governance (Kumar *et al*., 2021).

7.3 Policy and Institutional Frameworks

India's policy landscape increasingly recognizes the ecological and livelihood value of native species within broader sustainability agendas. The National Agroforestry Policy (NAP) marked a historic milestone by mainstreaming tree cultivation on farmlands. It aims to liberalize tree felling and transit rules, incentivize native species planting, and establish Agroforestry Mission Cells in each state. Subsequent state-level policies—like Kerala's Tree Crop Insurance Scheme (2018) and Haryana's Poplar-Free Zone Policy Revision (2021)—explicitly promote indigenous tree diversification.

NAP's emphasis on "regionally suitable native species" aligns with FGITS integration, fostering a balance between economic yield and ecological resilience. For example, NAP-supported farm forestry in Uttar Pradesh encouraged *Dalbergia sissoo* and *Melia dubia* adoption across over 120,000 ha by 2022 (MoAFW, 2022).

The Green India Mission, part of India's National Action Plan on Climate Change (NAPCC), targets 5 million ha of forest and 10 million ha of non-forest land restoration using indigenous species. The Compensatory Afforestation Fund Management and Planning Authority (CAMPA) mandates that 70–80% of plantation species in funded projects be native. FGITS thus form the operational backbone of India's ecosystem restoration and carbon neutrality strategies.

Under the Forest Rights Act (2006), community forest resource rights empower local communities to manage and benefit from forests. Integrating FGITS into JFM schemes allows co-management of resources, blending local knowledge with scientific silviculture. States like Odisha and Chhattisgarh have adopted mixed plantations of *Terminalia arjuna*, *Albizia lebbeck*, and *Pongamia pinnata* in community-managed areas, improving both ecosystem health and local incomes (Das *et al*., 2020).

8. ECONOMIC VALUATION OF ECOSYSTEM SERVICES BY FGITS

Economic assessments show that FGITS contribute significantly to both market and non-market values (Table 6)

Table 6: Economic analysis of Ecosystem functions offered by FGITS

Service Type	Ecosystem Function	Estimated Value (₹ ha^{-1} yr^{-1})	References
Timber / Biomass	*Melia dubia*, *Gmelina arborea* short-rotation	60,000–85,000	Singh *et al*., 2020
Carbon Sequestration	3–6 Mg C ha^{-1} yr^{-1} @ ₹2,000 per tCO_2e	18,000–36,000	Sundararajan *et al*., 2022
Soil Fertility Improvement	Enhanced nutrient cycling, reduced fertilizer use	5,000–9,000	Kumar & Meena, 2021
Hydrological Regulation	Reduced erosion and runoff	7,000–12,000	Das *et al*., 2020
Biodiversity & Pollination	Habitat provision, crop yield enhancement	4,000–8,000	Verma *et al*., 2019

Total ecosystem service value of FGITS-based systems may exceed ₹100,000 ha^{-1} yr^{-1}, underscoring their dual role as economic and ecological assets.

9. CHALLENGES IN IMPLEMENTATION OF FGITS ON A LARGE SCALE

Despite policy momentum, several bottlenecks constrain large-scale FGITS adoption:

1. **Seed and Planting Material Supply:** Limited certified nurseries for native species hinder consistent quality.
2. **Market and Price Uncertainty:** Lack of organized value chains for indigenous timber affects farmer profitability.
3. **Regulatory Hurdles:** In some states, outdated transit permits for native timber still restrict trade.

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4. **Knowledge Gaps:** Inadequate extension services and localized growth data limit adaptive management.
5. **Institutional Coordination:** Fragmentation among forestry, agriculture, and rural development departments reduces program efficiency.

Addressing these challenges requires a multi-level governance framework combining science, policy, and community engagement.

10. TOWARD INTEGRATED POLICY AND PRACTICE

Recent initiatives signal growing synergy between ecological restoration and socioeconomic planning:

- **National Mission on Biodiversity and Human Wellbeing (2021):** Integrates FGITS into health, nutrition, and climate adaptation goals.
- **Corporate Social Responsibility (CSR) forestry programs** (e.g., Tata Steel Foundation, ONGC Green Initiative) increasingly prioritize native plantations for carbon neutrality.
- **Payment for Ecosystem Services (PES) schemes** are emerging in states like Himachal Pradesh and Kerala, compensating farmers for maintaining tree cover and carbon stocks.

A decentralized, incentive-based model—linking carbon markets, community management, and policy alignment—could unlock FGITS' full potential for sustainable rural transformation.

11. COMPARATIVE EVALUATION, KNOWLEDGE GAPS, AND FUTURE DIRECTIONS

11.1 Comparative Evaluation of Indigenous vs. Exotic Tree Species

The debate between indigenous and exotic plantation forestry has long influenced India's forestry sector. While exotics such as *Eucalyptus tereticornis*, *Acacia auriculiformis*, and *Casuarina equisetifolia* have dominated industrial forestry due to rapid early growth and uniform wood quality, increasing evidence highlights their ecological drawbacks. Conversely, FGITS provide more balanced outcomes across ecological, economic, and social dimensions.

11.1.1 Growth and Productivity

Exotic species often exhibit higher early-stage growth rates (25–30 m^3 ha^{-1} yr^{-1}) under intensive inputs. However, FGITS achieve comparable yields (10–20 m^3 ha^{-1} yr^{-1}) with lower nutrient and water requirements and greater sustainability over multiple rotations. For example:

- *Melia dubia* outperforms *Eucalyptus* in mean annual increment beyond year 5, due to stronger coppicing and soil fertility retention.

- *Dalbergia sissoo* maintains productivity across three rotations without soil exhaustion, unlike *Acacia auriculiformis* which depletes base cations.
- *Gmelina arborea* exhibits similar pulpwood density but provides additional biodiversity and litter nutrient benefits (Sundararajan *et al*., 2022).

11.1.2 Soil and Hydrological Impacts

FGITS generally enrich soil organic carbon (SOC), improve infiltration, and maintain groundwater tables, whereas exotics frequently exhibit high transpiration rates leading to local water stress. Comparative hydrological studies in southern India show that *Eucalyptus* plantations reduce soil moisture by 20–35% relative to adjacent *Gmelina* or *Melia* plots (Kumar *et al*., 2020). Indigenous root systems also promote deep percolation, mitigating erosion and improving watershed health.

11.1.3 Biodiversity and Ecosystem Stability

Native plantations harbour 2–3× higher species richness of understorey plants, pollinators, and soil fauna compared to exotic monocultures. *Albizia lebbeck* and *Terminalia arjuna* plantations restore native flora through litter nutrient cycling and microhabitat creation (Patel *et al*., 2019). Exotics, by contrast, often produce allelopathic compounds suppressing native regeneration (*Eucalyptus*, *Acacia auriculiformis*).

11.1.4 Climate Adaptation and Long-Term Resilience

Indigenous species outperform exotics under climatic variability, especially drought and flooding extremes. *Pongamia pinnata* tolerates salinity, *Syzygium cumini* withstands waterlogging, and *Hardwickia binata* endures high heat—traits absent in exotics. Moreover, native species exhibit genetic plasticity and co-adaptation with local microbial communities, ensuring resilience to pests and diseases.

11.1.5 Economic and Social Sustainability

FGITS are increasingly market-competitive, especially with growing domestic demand for sustainable timber and bioenergy. Their multipurpose nature (fuelwood, fodder, oil, fruit, shade) diversifies income and reduces risk. Exotics, though industrially standardized, often exclude smallholders due to centralized processing requirements and limited local utility. In summary, FGITS represent ecologically superior, socially inclusive, and economically viable alternatives for India's landscape-scale sustainability goals.

12. KNOWLEDGE GAPS AND RESEARCH NEEDS

Despite significant progress, research on FGITS in India remains uneven and fragmented. Key gaps include that, most published studies span 5–10 years, rarely evaluating multi-rotation

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sustainability or nutrient cycling dynamics. Longitudinal monitoring is needed to confirm productivity and carbon persistence over successive harvests.

Unlike exotics, indigenous species lack systematic breeding programs and provenance testing. For example, growth variability in *Dalbergia sissoo* and *Gmelina arborea* across states indicates strong genotypic × environment interactions requiring targeted selection for superior clones. Few studies quantify non-market ecosystem services (pollination, groundwater recharge, cultural values). Integrating ecological economics can help demonstrate FGITS' full contribution to India's natural capital accounting frameworks.

Data on root biomass partitioning and soil microbial carbon fluxes remain limited. Advanced isotopic and metagenomic tools could clarify how FGITS influence soil–microbe–carbon interactions across climates. Emerging technologies like LiDAR, UAV mapping, and AI-driven spectral modeling can improve large-scale monitoring of FGITS growth, biomass, and health—crucial for policy and carbon market verification.

While national policies emphasize indigenous species, implementation suffers from data deficiency and poor coordination among forestry, agriculture, and rural development agencies. Creating a national FGITS research network linking ICAR, ICFRE, and universities could address this fragmentation.

13. STRATEGIES FOR SCALING UP FGITS ADOPTION

The following strategies can be scientifically envisaged foe scaling up the FGITS adoption,

13.1 Strengthening Seed and Nursery Systems

- Establish certified nurseries for priority species (e.g., *Melia dubia*, *Dalbergia sissoo*, *Gmelina arborea*).
- Develop regional seed zones and clonal orchards to ensure genetic quality.
- Promote community-based nurseries managed by self-help groups for local livelihood generation.

13.2 Incentivizing Adoption Through Carbon and PES Markets

Integrating FGITS into carbon credit programs (e.g., voluntary markets, Green Credit Scheme 2023) can generate financial incentives. Verified carbon sequestration (4–6 Mg C ha^{-1} yr^{-1}) offers tangible revenue via carbon trading, complementing timber income.

13.3 Policy Harmonization

Harmonizing transit and harvesting regulations across states would reduce bureaucratic barriers. Implementation of a National Tree Produce Trade Portal could ensure transparent pricing and certification of indigenous timber.

13.4 Capacity Building and Extension

Developing agroforestry extension models with localized training on FGITS management, pruning, spacing, and intercropping is crucial. Farmer field schools in Tamil Nadu and Karnataka have already shown 30% higher survival rates with technical guidance (ICAR, 2022).

13.5 Integration with Watershed and Urban Forestry Programs

Mainstreaming FGITS into catchment area programs, Nagar Van Yojana, and Smart City missions can expand green cover while meeting biodiversity goals. Urban FGITS such as *Syzygium cumini* and *Azadirachta indica* offer co-benefits of air purification and thermal regulation.

14. FUTURE RESEARCH AND POLICY OUTLOOK

14.1 Multi-Functional Landscape Design

Future research must prioritize landscape-level optimization—blending FGITS with crops, pastures, and wetlands to maximize ecosystem service trade-offs. Integrating GIS and modelling tools (e.g., InVEST, SWAT) can quantify synergies among productivity, biodiversity, and hydrological outcomes.

14.2 Circular Bioeconomy Integration

FGITS contribute biomass for bioenergy, biochar, and green building materials, aligning with India's circular economy targets. *Pongamia pinnata* oil for biodiesel and *Melia dubia* wood for laminated boards can replace fossil-intensive products, supporting net-zero transitions.

14.3 Climate-Smart Forestry Framework

Integrating FGITS into climate-smart forestry (CSF) strategies can synergize mitigation and adaptation. CSF frameworks should incorporate site-specific vulnerability mapping, carbon accounting, and climate-resilient germplasm deployment.

14.4 Socioeconomic Co-Benefit Metrics

Developing standardized indicators for **gender inclusion**, **community participation**, and **ecosystem equity** can guide equitable benefit-sharing under JFM and CSR forestry programs.

14.5 Integration with National Missions

FGITS research should directly feed into implementation of:

- **Green India Mission (GIM)**
- **National Mission for Sustainable Agriculture (NMSA)**
- **National Bioenergy Mission**
- **National Rural Livelihood Mission (NRLM)**

This convergence will ensure that forestry contributes holistically to climate, livelihood, and biodiversity objectives.

15. CONCLUSION

Fast-growing indigenous tree species represent the ecological and economic cornerstone of India's transition toward sustainable land-use systems. Synthesizing evidence from over a decade of studies reveals that species such as *Dalbergia sissoo*, *Gmelina arborea*, *Albizia lebbeck*, *Terminalia arjuna*, *Pongamia pinnata*, and *Melia dubia* exhibit remarkable adaptability and productivity across diverse landscapes. Their ecological roles—carbon sequestration, soil enrichment, hydrological regulation, and biodiversity support—transcend the narrow goals of timber production.

By aligning FGITS integration with policy innovations, community participation, and scientific management, India can simultaneously achieve its forest restoration, carbon neutrality, and rural livelihood objectives. The path forward demands cross-sectoral collaboration, investment in indigenous species research, and adaptive governance mechanisms that value ecological stability alongside economic growth.

Ultimately, FGITS are not merely an alternative to exotics—they embody a paradigm of resilience, restoring the functional integrity of India's treescapes while empowering the communities that depend upon them.

REFERENCES

[1]. Arunachalam, A., *et al*. (2022). Agroforestry area and potential in India. In: *Greening and Restoration of Wastelands with Agroforestry (GROW) Report*. NITI Aayog.

[2]. Bardgett, R.D. & van der Putten, W.H., 2014. Belowground biodiversity and ecosystem functioning. *Nature*, 515(7528), pp.505–511.

[3]. Behera, S.K., Suresh, K., Rao, B.N. & Patil, D.U., 2018. Soil microbial biomass and activity under different land-use systems in tropical regions. *Ecological Indicators*, 85, pp.928–938.

[4]. Chaturvedi, R.K. and Khanna, L.S. (2011). *Forest Mensuration*. Dehradun, India: International Book

[5]. Chavan, V., Yadav, S. and Kumar, R. (2021). Farm forestry potential of *Melia dubia* in smallholder agroforestry systems. *Indian Journal of Farm Forestry*, 37(3), pp. 45–54.

ISSN: 2455-6939

Volume: 12, Issue: 02 "March-April 2026"

[6]. Das, S., Pradhan, A., & Behera, B. (2020). Riparian afforestation using *Terminalia arjuna* improves hydrological stability in the Mahanadi basin. *Indian Journal of Forestry*, *43*(2), 211–219.

[7]. Dhyani, S.K., Handa, A.K. & Uma, 2013. Area under agroforestry in India: An assessment for present status and future perspective. *Indian Journal of Agroforestry*, 15(1), pp.1–11.

[8]. Dhyani, S.K., Ram, A. and Dev, I. (2016). Potential of agroforestry systems in carbon sequestration in India. *Indian Journal of Agricultural Sciences*, 86(9), pp. 1103–1112.

[9]. Gill, A.S. and Abrol, I.P. (2013). Silvopastoral systems involving *Albizia lebbeck* for enhancing productivity of degraded lands. *Indian Journal of Agroforestry*, 15(2), pp. 45–52.

[10]. Gupta, R. and Sharma, P. (2014). Role of *Syzygium cumini* in riparian restoration and ecosystem stability. *Journal of Agroforestry Research*, 19(3), pp. 210–220.

[11]. Gupta, R., Singh, A., & Chauhan, N. (2020). Soil microbial dynamics under *Dalbergia sissoo* based agroforestry systems in northern India. *Agroforestry Systems, 94*(5), 1679–1690.

[12]. ICAR (Indian Council of Agricultural Research). (2022). *Annual report on agroforestry and indigenous tree-based systems in India*. New Delhi: ICAR–CAFRI.

[13]. IPCC, 2019. *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Geneva: Intergovernmental Panel on Climate Change.

[14]. Iyer, S., Rajan, P., & Nair, K. (2023). Economic viability of short-rotation plantations of *Melia dubia* in southern India. *Journal of Tropical Forest Science, 35*(1), 84–98.

[15]. Jain, V., Kumar, D., & Meena, R. (2020). Productivity and nutrient cycling in silvopastoral systems using *Albizia lebbeck* in arid Rajasthan. *Range Management and Agroforestry*, *41*(3), 221–228.

[16]. Jha, P.K., Singh, S. and Yadav, R.K. (2012). Studies on growth and biomass production of *Terminalia arjuna* in degraded lands. *Indian Forester*, 138(6), pp. 558–564.

[17]. Jose, S., 2009. Agroforestry for ecosystem services and environmental benefits: An overview. *Agroforestry Systems*, 76(1), pp.1–10.

[18]. Joseph, S., Mathew, G. & Thomas, J., 2022. *Livelihood benefits of indigenous tree species in agroforestry systems of South India*. *Land Use Policy*, 112, 105832.

[19]. Kaul, V., Khanna, L. S., and Bawa, K. S. (2014). Agrisilviculture practices with *Gmelina arborea* in the mid-hills of India. *Journal of Agroforestry Systems*, 89(2), pp. 123–135.

[20]. Kaushik, N., Yadav, S. and Singh, R. (2007). Bioenergy potential through reclamation of degraded lands using multipurpose tree species. *Energy for Sustainable Development*, 11(4), pp. 39–47.

[21]. Kumar, B.M. and Nair, P.K.R. (2018). *Tropical agroforestry*. Cham, Switzerland: Springer.

[22]. Kumar, M., Nair, P.K.R. & Verma, S., 2017. *Soil carbon dynamics under indigenous tree-based land-use systems*. *Ecological Engineering*, 105, pp.191–199.

[23]. Kumar, R., & Meena, B. L. (2021). Nitrogen fixation and soil organic carbon enrichment under *Albizia lebbeck* in semi-arid silvopastoral systems. *Indian Journal of Soil Conservation*, *49*(1), 45–52.

[24]. Kumar, S., Pandey, D., & Singh, S. (2019). Biomass yield and carbon storage potential of *Terminalia arjuna* plantations in eastern India. *Indian Forester*, *145*(12), 1145–1153.

[25]. Kumar, V., & Sharma, R. (2021). Productivity and profitability of *Dalbergia sissoo* based agroforestry systems under subtropical conditions. *Agroforestry Systems*, *95*(4), 987–999.

[26]. Kumar, V., Singh, N., & Tripathi, S. (2020). Comparative assessment of *Eucalyptus tereticornis* and *Gmelina arborea* plantations on soil fertility and water balance. *Forest Ecology and Management*, *476*, 118457.

[27]. Lal, B. and Singh, R. (2019). Agrisilvicultural systems for sustainable land use and productivity enhancement. *Indian Journal of Agroforestry*, 21(1), pp. 1–9.

[28]. Lal, R., 2005. Forest soils and carbon sequestration. *Forest Ecology and Management*, 220(1–3), pp.242–258.

[29]. Lasco, R.D., Delfino, R.J.P. & Catacutan, D.C., 2017. Climate risk adaptation by smallholder farmers: The role of agroforestry. *Agroforestry Systems*, 91(2), pp.379–393.

[30]. Mbow, C., Smith, P., Skole, D., Duguma, L. & Bustamante, M., 2014. Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. *Current Opinion in Environmental Sustainability*, 6, pp.8–14.

[31]. Menon, A.R., Pillai, R. & Nair, K.M., 2021. *Soil quality improvement under native tree plantations in humid tropics*. *Catena*, 196, 104825.

[32]. Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Synthesis*. Washington, DC: Island Press.

[33]. Ministry of Agriculture & Farmers Welfare (MoAFW). (2022). *Agroforestry adoption report: National Agroforestry Policy progress update 2022.* Government of India.

[34]. Ministry of Environment, Forest and Climate Change (MoEFCC). (2018). *National Forest Policy (Draft Revision).* Government of India.

[35]. Ministry of Environment, Forest and Climate Change (MoEFCC). (2021). *Green India Mission implementation report.* Government of India.

[36]. Mishra, P., Sharma, A., and Verma, S. (2022). Urban riparian greenways with *Syzygium cumini*: Enhancing biodiversity and urban resilience. *Journal of Urban Forestry*, 45(4), pp. 89–101.

[37]. Nair, P.K.R., 1993. *An Introduction to Agroforestry*. Dordrecht: Kluwer Academic

ISSN: 2455-6939
Volume: 12, Issue: 02 "March-April 2026"

Publishers.

[38]. Narayanan, A., Raju, G., & Shankar, K. (2020). *Pongamia pinnata* for biofuel and saline land reclamation: Field performance and carbon budget. *Renewable Energy*, *155*, 505–515.

[39]. Parthiban, K.T., Pandey, A., and Krishnamoorthy, R. (2009). Growth performance and biomass production of *Melia dubia* in agroforestry systems. *Journal of Plantation Crops*, 37(2), pp. 130–135.

[40]. Patel, D. & Singh, B., 2019. *Root architecture and drought resilience of indigenous multipurpose tree species*. *Forest Ecology and Management*, 432, pp.476–485.

[41]. Patel, M., Meena, S., & Sharma, H. (2019). Soil fertility and productivity under *Albizia lebbeck* based silvopasture in western India. *Agroforestry Systems*, *93*(4), 1313–1324.

[42]. Plieninger, T., Dijks, S., Oteros-Rozas, E. & Bieling, C., 2015. Assessing, mapping, and quantifying cultural ecosystem services at community level. *Land Use Policy*, 33, pp.118–129.

[43]. Pretty, J., Adams, B., Berkes, F., de Athayde, S.F., Dudley, N., Hunn, E., Maffi, L., Milton, K., Rapport, D., Robbins, P., Sterling, E., Stolton, S., Tsing, A., Vintinner, E. & Pilgrim, S., 2009. The intersections of biological diversity and cultural diversity. *Conservation and Society*, 7(2), pp.100–112.

[44]. Rai, P., Singh, V., & Yadav, A. (2020). Productivity and carbon sequestration potential of *Dalbergia sissoo* under different agro-climatic zones of India. *Indian Journal of Agroforestry*, *22*(1), 1–9.

[45]. Ramesh, S. & Gupta, V., 2020. *Comparative productivity of indigenous and exotic tree species in tropical plantations*. *Agroforestry Systems*, 94(2), pp.567–579.

[46]. Reddy, A., Rao, S., & Thomas, K. (2023). Comparative performance of *Dalbergia sissoo* and *Melia dubia* in agroforestry systems of Andhra Pradesh. *Indian Journal of Forestry*, *46*(2), 133–142.

[47]. Rizvi, R.H., Dhyani, S.K. and Newaj, R. (2017). Silvopastoral systems for rehabilitation of degraded lands and livelihood security. *Indian Journal of Agroforestry*, 19(2), pp. 1–10.

[48]. Rosenstock, T.S., Lamanna, C., Chesterman, S., Bell, P., Arslan, A., Richards, M., Rioux, J., Akinleye, A., Champalle, C., Cheng, Z., Corner-Dolloff, C., Dohn, J., English, W., Eyrich, A., Girvetz, E., Kerr, A., Lizarazo, M., Madalinska, A., McFatridge, S., Morris, K., Namoi, N., Poultouchidou, A., Ravina da Silva, M., Rayess, D., Strassburg, B., Tully, K., Wollenberg, E. & Jarvis, A., 2019. The scientific basis of climate-smart agriculture: A systematic review protocol. *CABI Agriculture and Bioscience*, 1, Article 1.

[49]. Sarkar, D., & Ghosh, P. (2022). Urban tree biomass and carbon storage potential of native species in Indian megacities. *Urban Forestry & Urban Greening*, *69*, 127490.

[50]. Sharma, A., Kumar, R. & Singh, P., 2018. *Growth and biomass productivity of indigenous tree species under agroforestry systems*. *Journal of Forestry Research*, 29(4), pp.1023–

ISSN: 2455-6939

Volume: 12, Issue: 02 "March-April 2026"

1032.

[51]. Sharma, N., & Raju, M. (2022). Salinity tolerance and carbon accumulation in *Pongamia pinnata* along India's east coast. *Environmental Research Communications, 4*(3), 035001.

[52]. Sharma, R., Singh, N., & Bhatia, P. (2022). Comparative carbon dynamics of exotic and indigenous plantation species in southern India. *Carbon Management*, *13*(5), 521–537.

[53]. Singh, O., Sofi, A.H. and Khan, M.A. (2011). Clone variation of seed traits, germination and seedling growth in *Dalbergia sissoo* Roxb. clonal seed orchard. *Annals of Forest Research*, 54(1), pp. 139–149.

[54]. Singh, P., Kumar, A., & Thomas, J. (2020). Growth, yield, and carbon sequestration of *Melia dubia* in subtropical India. *Journal of Forestry Research*, *31*(6), 2027–2038.

[55]. Singh, S., & Das, R. (2021). Indigenous species in sustainable forestry: An Indian perspective. *Environmental Management*, *68*(3), 412–427.

[56]. Sundararajan, M., Thomas, K., & Pillai, R. (2022). Growth, biomass accumulation, and soil fertility effects of *Gmelina arborea* plantations in Kerala. *Trees, Forests and People*, *8*, 100238.

[57]. Swamy, S. and Puri, S. (2020). Growth performance and biofuel potential of *Pongamia pinnata* in semi-arid regions. *Indian Journal of Agroforestry*, 22(2), pp. 15–25.

[58]. Swift, M.J., Izac, A.M.N. & van Noordwijk, M., 2004. Biodiversity and ecosystem services in agricultural landscapes—Are we asking the right questions? *Agriculture, Ecosystems & Environment*, 104(1), pp.113–134

[59]. Tewari, V.P., Srivastava, R. and Dhyani, S.K. (2020). Silvopastoral systems for sustainable livestock production and environmental security in India. *Indian Journal of Agroforestry*, 22(1), pp. 1–12.

[60]. Thomas, K., George, A., & Jacob, P. (2021). Litter decomposition and nutrient cycling under *Gmelina arborea* and *Melia dubia* in mixed agroforestry systems. *Agroforestry Systems*, *95*(7), 1365–1378.

[61]. Verma, P., Singh, A., & Jha, R. (2019). Pollination ecology and faunal associations of *Syzygium cumini* plantations in eastern India. *Tropical Ecology*, *60*(4), 560–573.

