



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; SP-9(2): 01-08
Received: 02-11-2025
Accepted: 08-12-2025

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Agroforestry practices for sustainable production in India: A review

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i2Sa.4831>

Abstract

Agroforestry systems, which integrate crops and/or pasture lands with woody perennial trees, represent an effective land-use approach for sustaining agricultural productivity while maximizing returns from limited land resources. In India, agroforestry plays a vital role in enhancing farm productivity, improving livelihoods, and strengthening resilience through the simultaneous production of food, fodder, fuelwood, timber, and other ecosystem services. Owing to increasing pressure on land, declining soil fertility, and growing climate variability, agroforestry has emerged as an important area of interest for researchers, farmers, and policymakers. This review critically examines the contribution of major agroforestry practices in India with respect to (i) sustainable agricultural production, (ii) maintenance of ecological balance, (iii) soil carbon sequestration and climate change mitigation, and (iv) region-specific agroforestry systems that enhance system productivity and livelihood security. Multistoried and tree-based agroforestry systems, in particular, improve overall system productivity and soil nutrient status by enhancing biological activity through tree-crop interactions, biological nitrogen fixation, litter deposition, and efficient nutrient recycling. The synthesis of existing literature indicates that agroforestry systems in India significantly contribute to social, economic, and ecological sustainability by improving soil health, conserving biodiversity, enhancing carbon stocks, and diversifying farm income. Proper selection and management of tree and crop components are essential to minimize competition and maximize system benefits. This review highlights the need for location-specific research, improved management practices, and supportive policy interventions to strengthen agroforestry adoption and ensure long-term sustainability of Indian agriculture.

Keywords: Agroforestry systems, sustainable production, livelihoods, multistoried agroforestry, ecosystem services, India

1. Introduction

India is the most populous country in the world, with a population exceeding 1.4 billion, and faces immense pressure to ensure food and nutritional security for its rapidly growing population. Agriculture continues to play a vital role in supporting livelihoods and national food security. Although substantial progress has been made in cereal production since the Green Revolution, nutritional insecurity remains a major concern due to insufficient availability of fruits, vegetables, pulses, and other diversified food sources (FAO, 2021; Pingali *et al.*, 2019) ^[18, 42]. This challenge is further intensified by shrinking landholdings, population pressure, rapid urbanization, and degradation of natural resources (Chand *et al.*, 2017) ^[3].

India possesses approximately 156 million hectares of arable land; however, per capita availability of cultivable land has declined sharply over the decades (GOI, 2022). Intensive and continuous cultivation, excessive reliance on chemical fertilizers, monocropping, and inadequate residue and organic matter management have contributed to widespread soil degradation (Lal, 2015; Bhattacharyya *et al.*, 2016) ^[32, 1]. A large proportion of Indian agricultural soils are characterized by low soil organic carbon and deficiencies of essential nutrients such as nitrogen, phosphorus, potassium, and several micronutrients, including zinc and boron (Tandon, 2013; Singh *et al.*, 2020) ^[48, 47]. This decline in soil fertility poses a serious threat to long-term agricultural productivity and sustainability.

Soil health deterioration, coupled with increasing vulnerability to climate variability, presents a

significant challenge to Indian agriculture. The country frequently experiences climate-induced stresses such as droughts, floods, heat waves, cyclones, erratic rainfall patterns, and groundwater depletion across different agro-ecological regions (IPCC, 2022; Ramesh *et al.*, 2017) ^[24]. Climate change is projected to further exacerbate these stresses, adversely affecting crop productivity, farm incomes, and rural livelihoods (Mall *et al.*, 2018) ^[35]. Therefore, the adoption of climate-smart, resource-efficient, and resilient agricultural practices has become essential to ensure sustainable food production and environmental stability.

Agroforestry, a land-use system that deliberately integrates trees with crops and/or livestock, offers a promising solution to address these challenges. According to Nair (1993) ^[37] and Garrity (2004) ^[20], agroforestry systems provide multiple ecological, economic, and social benefits, including improved soil fertility through enhanced organic matter input and nutrient cycling, reduced soil erosion, improved microclimate regulation, biodiversity conservation, carbon sequestration, and diversified income opportunities. By optimizing both vertical and horizontal resource use, agroforestry enhances productivity per unit area while ensuring sustainable management of natural resources (Jose, 2009; Udawatta *et al.*, 2019) ^[25, 50].

Across India, diverse agroforestry systems such as agri-silviculture, agri-horticulture, agri-silvi-horticulture, silvipastoral systems, boundary and block plantations, and homestead agroforestry are widely practiced under different agro-climatic conditions (Dhyani *et al.*, 2013; Rizvi *et al.*, 2017) ^[17, 45]. Fruit-tree-based agroforestry systems involving mango, guava, aonla, ber, citrus, coconut, banana, and jackfruit integrated with annual crops, vegetables, and fodder species are particularly popular among small and marginal farmers (Chavan *et al.*, 2015; Kumar *et al.*, 2018) ^[8, 31]. These systems contribute significantly to year-round production, income diversification, food and nutritional security, and livelihood resilience.

Agroforestry also plays a crucial role in climate change mitigation and adaptation by enhancing carbon stocks, reducing greenhouse gas emissions, improving water-use efficiency, and buffering crops against climatic extremes (Montagnini & Nair, 2012; Lal *et al.*, 2018) ^[36, 33]. Recognizing its importance, agroforestry has been promoted through national initiatives such as the National Agroforestry Policy (2014), along with various programs under ICAR, the National Mission for Sustainable Agriculture (NMSA), and state-level schemes across the country (Dhyani *et al.*, 2018) ^[12].

While a considerable body of research in India highlights the role of agroforestry in improving productivity, soil fertility, livelihood security, and ecological sustainability (Pandey, 2007; Tewari *et al.*, 2019) ^[41, 49], comprehensive synthesis on its overall potential and scope at the national level remains limited. Therefore, the present review aims to assess the potential of agroforestry systems for sustainable agricultural production in India, summarize prevalent agroforestry practices, and evaluate their role in enhancing soil health, farm resilience, livelihoods, and climate change mitigation.

2. Common Agroforestry Practices in India

Agroforestry is a traditional and sustainable land-use system widely practiced across India, involving the deliberate integration of woody perennials with agricultural crops and/or livestock on the same land management unit. Rooted in indigenous farming knowledge and strengthened by scientific advancements in agroecology, agroforestry contributes to agricultural sustainability, enhanced productivity, livelihood

security, and environmental conservation (Nair, 1993; Leakey, 2017) ^[37, 34]. The system consists of three major components—trees, crops, and animals—forming three basic agroforestry systems, namely agrisilviculture, silvipastoral, and agri-silvipastoral systems.

India's diverse agro-climatic conditions support a wide range of agroforestry practices. Fruit orchards such as mango, guava, aonla, ber, citrus, banana, papaya, coconut, arecanut, litchi, and apple are expanding across different regions and offer immense scope for conversion into scientifically managed agroforestry systems (Chavan *et al.*, 2015) ^[9]. Fast-growing multipurpose tree species such as poplar, eucalyptus, neem, shisham, teak, subabul, bamboo, and casuarina are commonly integrated with agricultural crops (Dhyani *et al.*, 2013) ^[14]. Boundary plantation, block plantation, alley cropping, cropland agroforestry, multistoried systems, silvipastoral systems, homestead agroforestry, shelterbelts, and windbreaks are the most prevalent agroforestry practices in India, contributing significantly to sustainable agricultural production and climate resilience.

2.1 Alley Cropping / Hedgerow Intercropping

Alley cropping, also known as hedgerow intercropping, involves growing agricultural crops between rows of trees or shrubs. According to Kang *et al.* (1990) ^[26] and Young (1997) ^[51], this system enhances land productivity by combining short-term crop benefits with long-term tree outputs. In India, alley cropping is particularly suitable for rainfed, semi-arid, and hilly regions where soil conservation and moisture retention are critical (ICAR, 2016).

Common tree species include *Leucaena leucocephala*, *Gliricidia sepium*, *Sesbania sesban*, *Albizia lebbeck*, and *Calliandra calothyrsus*, while crops such as cereals, pulses, oilseeds, vegetables, and fodder crops are grown in the alleys. Although competition may occur, several studies have reported land equivalent ratios (LER) greater than one, indicating superior system productivity compared to monocropping (Rao *et al.*, 2012) ^[44]. Proper alley width, periodic pruning, and species selection significantly reduce competition and enhance system efficiency (Jose, 2009) ^[25].

Pruned biomass acts as green manure and mulch, improving soil organic carbon, moisture retention, and microbial activity while reducing dependence on chemical fertilizers, particularly nitrogen (Palm *et al.*, 2014) ^[39].

2.2 Shifting Cultivation-Based and Sloping Land Agroforestry Systems

Shifting cultivation (jhum) practiced in northeastern India has become ecologically unsustainable due to shortened fallow periods (Ramakrishnan, 1992) ^[43]. Agroforestry-based alternatives such as agri-horticulture, contour hedgerows, and silvipastoral systems have been shown to reduce soil erosion, enhance biomass production, and improve farm incomes (Darlong & Tripathi, 2012; Singh *et al.*, 2018) ^[11, 1]. To address these challenges, agroforestry-based alternatives such as agri-horticulture, agri-silviculture, silvipastoral systems, contour-based tree planting, and sloping agricultural land technologies have been promoted in hilly and sloping regions of India. These systems integrate perennial trees with crops to stabilize soil, reduce runoff, enhance soil fertility, and improve productivity. Compared to traditional shifting cultivation, agroforestry-based land-use systems have demonstrated reduced soil erosion, increased biomass production, and improved economic returns, thereby offering sustainable livelihood options while conserving fragile ecosystems.

2.3 Cropland Agroforestry

Cropland agroforestry is one of the most widespread and economically important agroforestry systems in India. In this system, farmers integrate trees within agricultural fields to produce timber, fuelwood, fodder, fruits, medicinal products, and ecological benefits alongside food crops. Common tree species include poplar, eucalyptus, neem, shisham, teak, subabul, bamboo, mango, guava, aonla, jamun, and coconut. Cropland agroforestry systems are predominantly adopted by small and marginal farmers to diversify income sources and reduce production risks. In these systems, crops primarily utilize nutrients from the upper soil layers, while trees extract water and nutrients from deeper layers, reducing direct competition. Appropriate spacing, species selection, and management practices are crucial to maintaining crop productivity. Leaf litter and pruned biomass contribute significantly to soil organic matter and nutrient cycling, leading to improved soil fertility and structure over time. Agroforestry is recognized as a key strategy for climate change mitigation and adaptation. According to the Intergovernmental Panel on Climate Change (IPCC), agroforestry has one of the highest potentials for carbon sequestration among agricultural land-use systems. Cropland agroforestry systems capture atmospheric carbon dioxide and store carbon in biomass and soil, while enhancing resilience against climate extremes such as droughts, floods, and heat stress. Economic analyses consistently show higher net returns from agroforestry-based systems compared to sole cropping, reinforcing their role in improving farmer livelihoods and ecosystem services. Cropland agroforestry is among the most widespread systems in India, particularly in the Indo-Gangetic Plains. Studies by Singh *et al.* (2017) ^[46] and Tewari *et al.* (2019) ^[49] reported higher net returns and improved soil health under poplar- and eucalyptus-based agroforestry compared to sole cropping. According to IPCC (2019) ^[23], agroforestry has one of the highest carbon sequestration potentials among agricultural land-use systems.

2.4 Agri-silviculture System

The agri-silviculture system involves the cultivation of agricultural crops alongside forest or multipurpose tree species to increase land productivity and economic returns. Across India, crops such as rice, wheat, maize, pulses, oilseeds, vegetables, and fodder crops are commonly grown under tree species like poplar, eucalyptus, shisham, neem, teak, albizia, and subabul. Poplar- and eucalyptus-based agri-silviculture systems are particularly prominent in northern and northwestern India due to their compatibility with cereal-based cropping systems. Agri-silviculture systems involving poplar, eucalyptus, shisham, and neem integrated with cereal crops are well established in northern India. Research by Chaturvedi *et al.* (2014) ^[5] showed higher benefit–cost ratios and improved nutrient cycling in these systems compared to monocropping.

2.5 Multistoried Agroforestry Systems

Multistoried agroforestry systems are highly productive land-use systems that involve the vertical arrangement of trees and crops in multiple canopy layers. These systems typically consist of upper-storey timber or fruit trees, middle-storey plantation or fruit crops, and lower-storey vegetables, spices, fodder, or medicinal plants. Multistoried agroforestry systems are commonly found in homesteads, orchards, plantations, and tribal farming systems across India. Typical multistoried combinations include coconut–banana–pineapple, arecanut–pepper–banana, mango–guava–vegetables, aonla–lemon–ginger, citrus–papaya–turmeric, and poplar–banana–vegetables. These systems efficiently utilize solar radiation, soil nutrients, and moisture by exploiting different canopy strata and root zones. Multistoried agroforestry systems are among the most efficient land-use systems, particularly in humid and sub-humid regions. According to Nair (2011) ^[38] and Kumar *et al.* (2018) ^[29], these systems maximize resource-use efficiency, carbon sequestration, and income diversification. Higher LER and BCR values reported by Pandey (2007) ^[41] and Rizvi *et al.* (2017) ^[45] confirm their superiority over monocropping systems.

Table 1: Agroforestry systems addressing climate change impacts in different regions of India

Agroforestry systems	Applicable regions in India	Climate-smart functions
Cropland agroforestry	Indo-Gangetic Plains, Central India, Western and Southern India	Enhances climate resilience, carbon sequestration, diversification of income, protection against heat and moisture stress
Agri-horticultural system	Plains and semi-arid regions	Improves food and nutritional security, carbon sequestration, livelihood diversification
Multistoried agroforestry systems	Humid tropics, Eastern and Northeastern India, homesteads and uplands	Conservation of agrobiodiversity, carbon sequestration, efficient resource utilization
Agri-horti-silvicultural system	Hilly and undulating regions (Himalayan foothills, Central Indian plateau)	Reduces soil erosion and landslides, improves soil fertility, carbon storage
Planting crops under tree stands	Throughout India	Carbon sequestration, microclimate moderation, yield stability
Use of live barriers (windbreaks, shelterbelts, live fencing)	Coastal regions, arid and semi-arid zones, cyclone- and wind-prone areas	Protection from wind erosion and cyclones, moisture conservation, resilience to extreme weather
Silvipastoral systems	Drylands, arid and semi-arid regions	Fodder security, carbon sequestration, land restoration
Aquaforestry	Coastal belts, flood-prone and wetland regions	Climate change mitigation, carbon sequestration, diversified livelihood options

Table 2: Common tree crop combinations in cropland agroforestry systems in India

Tree species	Associated horticultural/agricultural crops
Fruit trees	
<i>Mangifera indica</i> (Mango)	Rice, wheat, maize, mustard, pulses, vegetables, turmeric, ginger
<i>Psidium guajava</i> (Guava)	Vegetables, pulses, fodder crops
<i>Phyllanthus emblica</i> (Aonla)	Wheat, mustard, pulses, vegetables
<i>Citrus</i> spp.	Banana, papaya, vegetables, pulses
<i>Cocos nucifera</i> (Coconut)	Paddy, banana, pineapple, vegetables
<i>Artocarpus heterophyllus</i> (Jackfruit)	Banana, ginger, turmeric, vegetables

Woody / multipurpose trees	
<i>Populus deltoides</i> (Poplar)	Wheat, sugarcane, potato, fodder crops
<i>Eucalyptus</i> spp.	Wheat, mustard, pulses, fodder crops
<i>Dalbergia sissoo</i> (Shisham)	Wheat, mustard, vegetables
<i>Azadirachta indica</i> (Neem)	Cereals, pulses, vegetables
<i>Leucaena leucocephala</i> (Subabul)	Fodder crops, pulses
<i>Albizia lebbeck</i>	Turmeric, banana, vegetables
<i>Acacia</i> spp.	Pulses, oilseeds
<i>Tectona grandis</i> (Teak)	Vegetables, pulses (early years)
<i>Bambusa</i> spp. (Bamboo)	Vegetables, fodder, medicinal plants

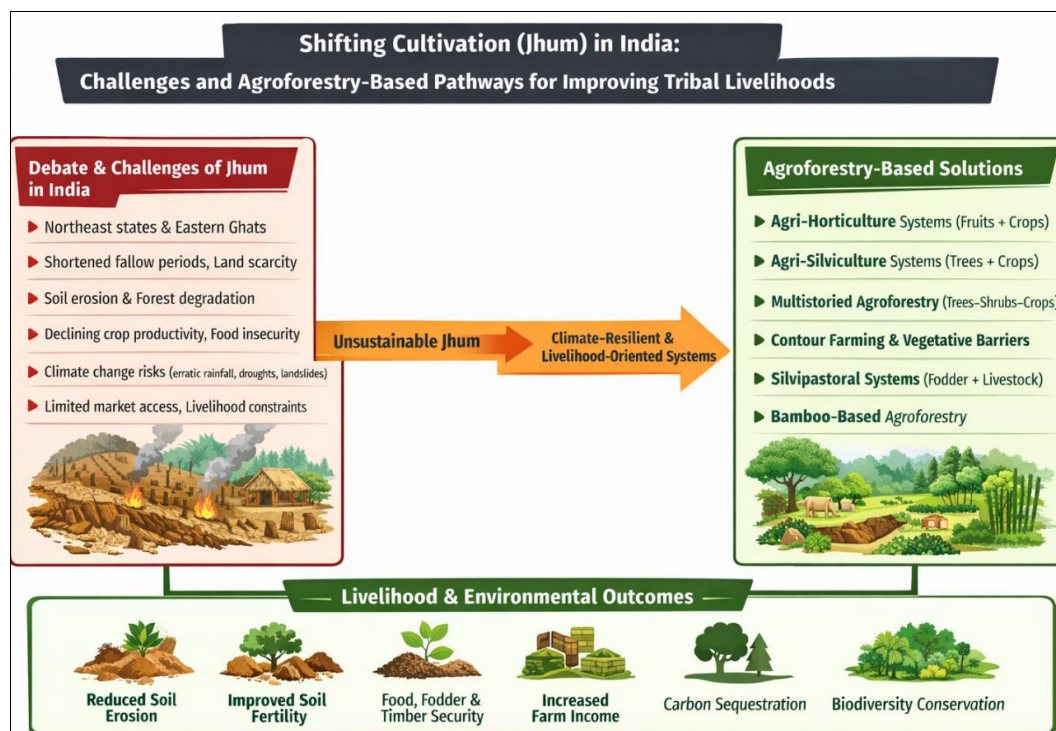


Fig 1: Debate about jhum and possible ways to improve jhumias' livelihood

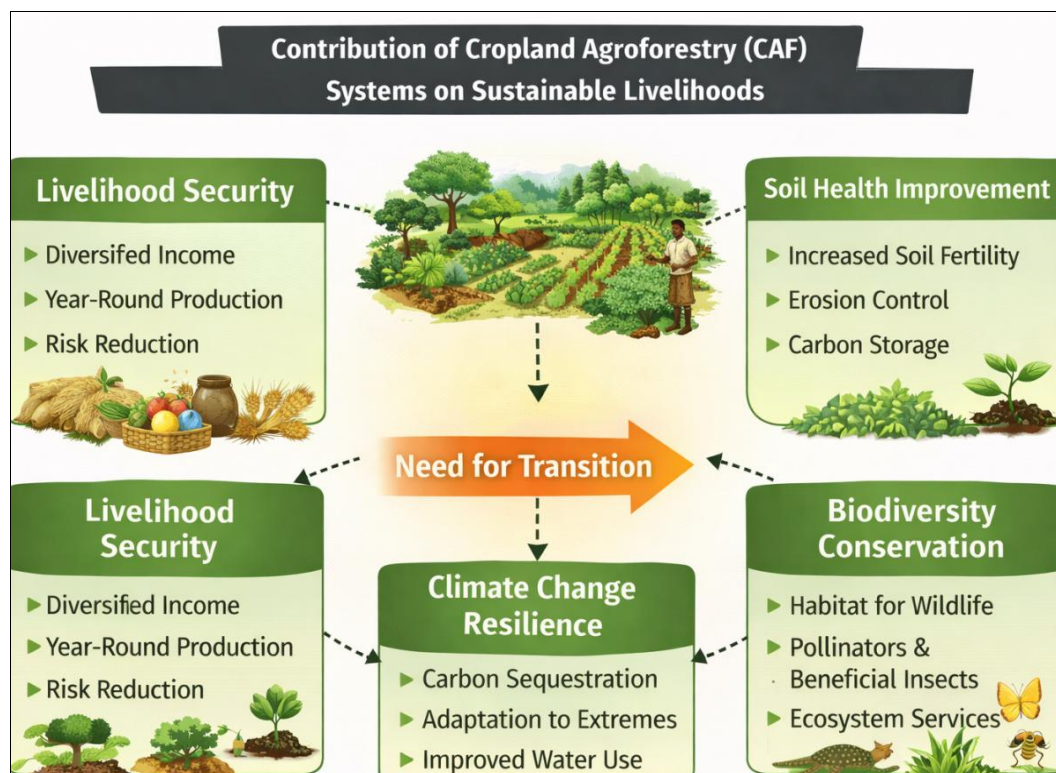


Fig 2: Contribution of CAF on sustainable livelihood

2.6 Homestead Agroforestry (India)

Homestead agroforestry in India consists of the homestead area and its adjoining land managed by farm families, where multistoried vegetation comprising fruit trees, timber species, shrubs, palms, bamboos, vegetables, spices, medicinal plants, and fodder crops are integrated with livestock components such as cattle, buffalo, goats, poultry, and ducks. Such systems represent a complex land-use practice that closely mimics natural forest structures while ensuring continuous production of multiple outputs (Nair, 1993; Kumar & Nair, 2004) ^[37, 28]. These systems are widespread across rural and peri-urban India, particularly in states such as Uttar Pradesh, West Bengal, Bihar, Odisha, Assam, Kerala, Tamil Nadu, and the northeastern region, where small and marginal farmers dominate the agrarian landscape (Pandey, 2007; Dhyani *et al.*, 2013) ^[40, 13].

Homestead agroforestry provides a wide range of products, including fuelwood, fruits, vegetables, fodder, timber, bamboo, medicinal resources, livestock products, and shelter, thereby supporting household subsistence and income generation. Studies have shown that Indian home gardens significantly contribute to daily household consumption and act as a safety net during periods of crop failure or market instability (Jose, 2009; Rizvi *et al.*, 2017) ^[25, 45].

In India, homesteads are traditionally divided into functional micro-sites such as the front yard, backyard, side yard, boundary plantation, kitchen garden, and approach areas, each hosting specific plant species based on light availability, water access, and household needs. This spatial arrangement enhances resource-use efficiency and species complementarity, thereby improving overall system productivity (Kumar *et al.*, 2012) ^[30]. Homestead agroforestry, commonly referred to as home gardening, represents one of the oldest and most resilient traditional land-use systems in tropical India and plays a crucial role in the rural economy by ensuring food and nutritional security, particularly for small and marginal farmers (Nair, 2011; Pandey, 2007) ^[38, 41].

Due to small landholdings, population pressure, and livelihood constraints, rural households increasingly intensify the use of homestead spaces as productive units. In many regions of India, homestead agroforestry contributes significantly to domestic requirements of fruits, vegetables, fuelwood, fodder, bamboo, and minor forest produce, thereby reducing dependence on external markets and pressure on nearby forests (Chaturvedi *et al.*, 2014) ^[6]. Empirical studies across eastern and southern India have reported high species richness in home gardens, reflecting strong linkages between homestead structure, socio-economic status, soil conditions, and local ecology (Kumar & Nair, 2004; Udawatta *et al.*, 2019) ^[28, 50].

Homestead agroforestry systems also serve as important reservoirs of agrobiodiversity and play a vital role in the conservation of indigenous plant species, traditional crop varieties, and medicinal plants. In climatically vulnerable regions such as eastern India, coastal belts, and the northeastern states, homestead agroforestry contributes to climate resilience by buffering households against extreme weather events, salinity ingress, floods, and droughts (Ramakrishnan, 1992; Mall *et al.*, 2018) ^[43, 35].

Malnutrition remains a serious concern among landless laborers, smallholders, women, and children in rural India. Homestead agroforestry addresses this challenge by enabling year-round production of nutrient-rich fruits, vegetables, and animal products, thereby improving dietary diversity and household nutrition (FAO, 2021; Singh *et al.*, 2020) ^[18, 47]. Furthermore, homestead-based activities provide employment and income

opportunities for women, enhancing their economic participation, decision-making power, and social status within households and communities (Chand *et al.*, 2017) ^[4].

Given its multifunctional role, homestead agroforestry deserves greater recognition under national and state-level programs. Support through quality planting material, technical training, extension services, access to credit, and policy incentives can significantly enhance its contribution to biodiversity conservation, livelihood security, and sustainable rural development. Under present socio-economic and environmental conditions, homestead agroforestry represents a cost-effective, climate-resilient, and socially inclusive land-use system capable of meeting diverse household needs related to food, nutrition, energy, income, and employment (Dhyani *et al.*, 2018; Chavan *et al.*, 2015) ^[12, 8].

3. Benefits of Agroforestry and Ecosystem Services (India)

Integrating trees, crops, and livestock within agroforestry systems offers substantial ecological, economic, and social benefits across diverse agro-climatic regions of India. Agroforestry systems enhance soil fertility, biodiversity conservation, carbon sequestration, microclimate regulation, and livelihood resilience, while providing ecosystem services at multiple spatial and temporal scales (Jose, 2009; Garrity, 2004) ^[25, 20].

3.1 Biodiversity Conservation

Despite its rich biological heritage, India is experiencing rapid biodiversity loss due to agricultural intensification, monocropping, deforestation, and land-use change. Continuous cultivation of a limited number of crops has reduced agricultural biodiversity, negatively affecting ecosystem services, nutritional security, and farm resilience (IPBES, 2019) ^[22]. However, agricultural landscapes in India still hold immense potential for biodiversity conservation when managed through tree-based farming systems (Pandey, 2007) ^[40].

Agroforestry systems promote biodiversity conservation by providing habitats for diverse flora and fauna capable of tolerating moderate disturbance, conserving germplasm of indigenous and rare species, reducing pressure on natural forests, and supporting ecosystem services such as pollination, pest regulation, soil conservation, and water recharge (Jose, 2009; Udawatta *et al.*, 2019) ^[25, 50]. Several studies across India have documented higher species richness, functional diversity, and ecosystem stability in agroforestry systems compared to monocropping systems (Rizvi *et al.*, 2017; Singh *et al.*, 2017) ^[45, 46].

3.2 Increasing Soil Fertility

Soil fertility degradation is a major constraint to sustainable agriculture in India, particularly in rainfed, degraded, and intensively cultivated regions. Agroforestry enhances soil fertility through biological nitrogen fixation, efficient nutrient cycling, deep nutrient uptake, organic matter addition, and improved soil structure (Young, 1997; Lal, 2015) ^[51, 32].

Both nitrogen-fixing and non-nitrogen-fixing tree species contribute to improved physical, chemical, and biological soil properties. Agroforestry systems such as alley cropping, silvipasture, boundary plantations, windbreaks, and riparian buffers have demonstrated higher soil organic carbon, microbial biomass, enzyme activity, and macrofaunal abundance compared to conventional monocropping systems (Bhattacharyya *et al.*, 2016; Rao *et al.*, 2012) ^[1, 44]. Additionally, agroforestry practices help reduce nutrient losses, improve water

infiltration, and mitigate soil erosion, thereby supporting long-term soil health and sustainable productivity (Lal *et al.*, 2018) [33].

3.3 Climate Change Mitigation (Carbon Sequestration)

Agroforestry systems play a vital role in climate change mitigation and adaptation by enhancing carbon sequestration in both above-ground biomass and soils. In India, agroforestry offers a practical land-based mitigation strategy with multiple co-benefits such as food security, income diversification, land restoration, and reduced dependence on natural forests (Kumar *et al.*, 2018; Montagnini & Nair, 2012) [29, 36].

Agroforestry sequesters carbon by storing it in trees, crops, litter, roots, and soil organic matter, while also reducing greenhouse gas emissions through improved land management. Compared to monocropping systems, agroforestry systems have significantly higher carbon stocks and greater long-term carbon storage potential (Nair, 2011; Lal *et al.*, 2018) [38, 33]. Recognized under the National Agroforestry Policy (2014), agroforestry

aligns with India's commitments to creating additional carbon sinks and achieving climate-resilient agriculture (Chavan *et al.*, 2015; IPCC, 2022) [9, 24].

3.4 Ecosystem Services

Agroforestry systems in India provide a wide range of ecosystem services, including provisioning (food, fuel, fodder, timber), regulating (climate regulation, erosion control, water purification), supporting (nutrient cycling, soil formation), and cultural services (traditional knowledge, aesthetics, and livelihood identity) (Jose, 2009; FAO, 2021) [25, 19].

As a traditional and adaptive land-use practice, agroforestry enhances climate resilience, improves landscape stability, and supports multifunctional agriculture. Well-managed agroforestry landscapes contribute to ecological restoration, biodiversity conservation, sustainable livelihoods, and long-term agricultural sustainability across diverse Indian agro-ecosystems (Pandey, 2007; Dhyani *et al.*, 2013) [41, 14].

Table 3: Contribution of agroforestry to climate-smart agriculture in India

Pillar of CSA	Climate change strategy	Key functions	Role of agroforestry in India
Productivity	Practices that enhance food and nutritional security while sustaining natural resources	Increase and stabilize production through efficient land use	Agroforestry systems in India provide diversified outputs such as food grains, fruits, vegetables, fodder, fuelwood, timber, and non-timber forest products, ensuring year-round income and nutritional security. Integration of multipurpose tree species improves soil organic carbon, nutrient availability, water-use efficiency, and overall land productivity, particularly on small and marginal farms.
Adaptation	Actions that reduce vulnerability and enhance resilience to climate variability and extremes	Mitigate climate risks and improve system resilience	Agroforestry enhances resilience by functioning as shelterbelts and windbreaks, reducing damage from heat waves, droughts, floods, cyclones, and frost. Tree-based systems improve soil moisture retention, reduce evapotranspiration, and enhance groundwater recharge. Increased habitat diversity supports pollinators, natural enemies, birds, and beneficial insects, while diversified production systems reduce farmers' dependency on a single crop and lower climate-related risk.
Mitigation	Measures that reduce greenhouse gas emissions or increase carbon storage	Reduce GHG emissions and enhance carbon sequestration	Agroforestry increases tree cover outside forests, contributing significantly to carbon sequestration in above-ground biomass and soils. Tree integration reduces pressure on natural forests by supplying fuelwood, fodder, and timber, thereby conserving existing forest carbon stocks. Improved forage quality in silvopastoral systems lowers methane (CH ₄) emissions from livestock, while enhanced nutrient uptake and recycling by trees reduces nitrous oxide (N ₂ O) emissions from agricultural soils.

Food security, land tenure security, enhanced farm-based incomes, sustainable management of terrestrial and soil biodiversity, development of carbon sinks, regulation of hydrological functions, maintenance of wildlife corridors, reduction of soil erosion, biodiversity conservation, microclimate moderation, improved nutrient retention through root capture and recycling, and several other ecosystem services have been widely reported from different agro-ecological regions of India. Evidence from hilly and rainfed regions of India indicates that nutrient depletion due to soil erosion is considerably lower under agroforestry systems compared to shifting cultivation and slash-and-burn agriculture practiced in parts of the northeastern and eastern regions. Numerous studies across India demonstrate that agroforestry promotes sustainable agricultural production by supplying diverse household products, conserving natural resources, enhancing aquifer recharge, improving soil moisture dynamics, and stabilizing farm productivity.

Harnessing the mitigation potential of land-use sectors is essential for achieving India's emission reduction and climate commitments. Promotion of diverse agroforestry systems across different agro-climatic zones of the country can facilitate the productive use of marginal and low-fertility lands that currently exhibit poor agricultural performance. This can be achieved

through improvements in soil health, enhancement of water-use efficiency, and establishment of long-term carbon sinks within agricultural landscapes. Consequently, agroforestry contributes significantly to strengthening the resilience and adaptability of rainfed and dryland farming systems, which constitute a substantial portion of Indian agriculture.

4. Future Perspective

In India, commercial fruit orchards such as mango, guava, citrus, aonla, banana, apple, and pomegranate have expanded rapidly across diverse agro-ecological zones. These orchards offer immense opportunities for conversion into integrated agroforestry systems, which can simultaneously address micronutrient deficiencies, food and nutritional security, income diversification, and sustainability of farming systems (Kumar & Nair, 2004; Dhyani *et al.*, 2013) [28, 17]. Therefore, both traditional and improved agroforestry practices deserve greater attention at national and state levels due to their proven economic, ecological, and social benefits (Pandey, 2007; Rizvi *et al.*, 2017) [40, 45]. Traditional agroforestry systems can enhance social stability by strengthening farmer participation, promoting community-based land management, integrating indigenous knowledge with scientific innovations, and optimizing the use of natural resources (Jose, 2009; Kumar *et al.*, 2012) [25, 27]. These

systems also provide multifunctional landscapes that support local livelihoods, conserve biodiversity, and improve farm resilience (Chavan *et al.*, 2015; Dhyani *et al.*, 2018) ^[10, 15].

Given India's high vulnerability to climate change, increasing incidences of floods, droughts, heat waves, and declining air quality underscore the need for cost-effective and nature-based mitigation strategies (Mall *et al.*, 2018; Chaturvedi *et al.*, 2014) ^[35, 7]. Agroforestry systems can reduce flood risks, improve air quality, stabilize soils, regulate hydrological processes, and minimize riverbank and landscape erosion (Udawatta *et al.*, 2019; Lal, 2015) ^[50, 33]. The effectiveness of these services depends on tree species composition, spatial arrangement, planting density, age structure, and management practices adopted within agroforestry systems (Nair, 1993; Montagnini & Nair, 2012) ^[37, 36]. Furthermore, global assessments by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019) ^[22] emphasize that biodiversity conservation is critical for ensuring food security, climate change mitigation, reduced land degradation, and long-term environmental stability. In India, biodiversity loss has been driven by agricultural intensification, population growth, industrialization, habitat degradation, and climate change (Ramakrishnan, 1992; Young, 1997) ^[43, 51]. Agroforestry mimics the structural complexity of natural ecosystems by providing diverse habitats and refuges for flora and fauna, thereby contributing to biodiversity conservation and enhancement within agricultural landscapes (Kumar *et al.*, 2012; Dhyani *et al.*, 2018) ^[27, 16]. Adoption of agroforestry can also help mitigate the adverse impacts of deforestation and unsustainable land-use practices (Lal *et al.*, 2018; Kumar *et al.*, 2018) ^[27, 33].

5. Conclusion

Climate-smart agricultural practices such as agroforestry represent an indispensable pathway for achieving sustainable agricultural production, enhanced livelihoods, climate change mitigation, and adaptation in India. The present synthesis highlights that farmers across different regions of the country practice a wide range of agroforestry systems, reflecting both traditional knowledge and adaptive innovations. Systematic documentation and evaluation of these practices are crucial for strengthening the knowledge base on agroforestry and facilitating the wider adoption of suitable systems at the farm level, as well as for guiding future research and development efforts.

Effective management of tree-crop interactions through appropriate species selection, spacing, pruning, and silvicultural interventions is essential to minimize above- and below-ground competition and to enhance overall system productivity. Extension agencies, particularly the Department of Agriculture and allied institutions in India, play a pivotal role in promoting agroforestry through awareness campaigns, capacity-building programs, supply of quality planting material, and policy support. Strengthening these initiatives will accelerate the adoption of agroforestry as a sustainable, resilient, and climate-smart land-use system capable of addressing India's food security, environmental, and livelihood challenges.

References

1. Bhattacharyya R, Chakraborty D, Prakash V. Soil health improvement through agroforestry in India. *Agroforestry Systems*. 2016;90:443-456.
2. Bhattacharyya R, Kundu S, Prakash V, Gupta HS. Sustainability under combined application of mineral and organic fertilizers in a rainfed soybean-wheat system of the Indian Himalayas. *European Journal of Agronomy*. 2016;28:33-46.
3. Chand R, Sharma A, Singh S. Women and homestead agroforestry: Empowerment through productive landscapes. *Journal of Rural Studies*. 2017;50:100-108.
4. Chand R, Srivastava SK, Singh J. Changing structure of rural economy of India: Implications for employment and growth. *Economic & Political Weekly*. 2017;52(52):10-13.
5. Chaturvedi RK, Joshi PK, Kumar V, Ghosh S. Climate change vulnerability of Indian agriculture: Spatial assessment and adaptation strategies. *Environmental Management*. 2014;54:913-927.
6. Chaturvedi OP, Handa AK, Tripathi KP. Agroforestry systems for resource conservation and livelihood security in India. *Indian Journal of Agroforestry*. 2014;16(1):1-10.
7. Chaturvedi RK, Aggarwal PK, Srinivasan G. Climate change and agricultural sustainability in India: The role of agroforestry. *Current Science*. 2014;106(1):35-45.
8. Chavan S, Dhyani SK, Rawat PS. Multifunctional agroforestry systems for sustainable livelihoods. *Indian Journal of Agroforestry*. 2015;17(1):1-9.
9. Chavan BL, Soman MK, Patil BR. Policy interventions for promoting agroforestry in India. *Indian Journal of Agroforestry*. 2015;17(2):1-10.
10. Chavan SB, Keerthika A, Dhyani SK, Handa AK, Newaj R, Rajarajan K. National Agroforestry Policy in India: A low hanging fruit. *Current Science*. 2015;108(10):1826-1834.
11. Darlong VT, Tripathi RS. Soil organic carbon dynamics in slash-and-burn agriculture of Northeast India. *Agriculture, Ecosystems & Environment*. 2012;152:70-76.
12. Dhyani SK, Chavan S, Nautiyal S. Agroforestry in India: Sustainability and resilience perspectives. *International Journal of Agroforestry*. 2018;20:15-28.
13. Dhyani SK, Nautiyal S, Joshi PK. Agroforestry systems in India: Past, present and future. *Indian Journal of Agricultural Sciences*. 2013;83(7):722-731.
14. Dhyani SK, Newaj R, Sharma AR. Agroforestry: Its relation with agronomy, challenges and opportunities. *Indian Journal of Agronomy*. 2013;58(3):1-14.
15. Dhyani SK, Rizvi RH, Handa AK. National Agroforestry Policy of India: Challenges and strategies for implementation. *Indian Journal of Agroforestry*. 2018;20(1):1-10.
16. Dhyani SK, Nautiyal S, Rawat LS. Agroforestry for biodiversity conservation and livelihood security in India. *Agroforestry Systems*. 2018;92:1-16.
17. Dhyani SK, Sharma N, Nautiyal S. Role of agroforestry in livelihood security and environmental sustainability in India. *Indian Journal of Agroforestry*. 2013;15(1):1-12.
18. FAO. Home gardens for nutrition and livelihood security: India perspective. Rome: Food and Agriculture Organization of the United Nations; 2021.
19. FAO. The state of food security and nutrition in the world. Rome: Food and Agriculture Organization of the United Nations; 2021.
20. Garrity DP. Agroforestry and the achievement of the Millennium Development Goals. *Agroforestry Systems*. 2004;61:5-17.
21. Government of India. Agricultural statistics at a glance. New Delhi: Ministry of Agriculture & Farmers Welfare; 2022.
22. IPBES. Global assessment report on biodiversity and ecosystem services. Bonn: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services;

- 2019.
23. IPCC. Climate change and land: An IPCC special report. Geneva: Intergovernmental Panel on Climate Change; 2019.
24. IPCC. Sixth assessment report (AR6): Impacts, adaptation and vulnerability. Cambridge: Cambridge University Press; 2022.
25. Jose S. Agroforestry for ecosystem services and environmental benefits: An overview. *Agroforestry Systems*. 2009;76:1-10.
26. Kang BT, Reynolds L, Atta-Krah AN. Alley farming. *Advances in Agronomy*. 1990;43:315-359.
27. Kumar BM, Nair PKR, Mohan Kumar BR. Traditional and scientific approaches to agroforestry in India. *Current Science*. 2012;102(2):152-160.
28. Kumar BM, Nair PKR. The enigma of tropical homegardens. *Agroforestry Systems*. 2004;61:135-152.
29. Kumar BM, Nair PKR, Kunhamu TK. Carbon sequestration potential of agroforestry systems in India. *Current Science*. 2018;114(10):2114-2125.
30. Kumar BM, Nair PKR, Mohan R. Traditional and modern home gardens in India: Productivity and biodiversity conservation. *Agroforestry Systems*. 2012;86:189-206.
31. Kumar BM, Ravindranath NH, Nair PKR. Carbon sequestration potential of Indian agroforestry systems. *Agroforestry Systems*. 2018;92:891-906.
32. Lal R. Restoring soil quality to mitigate soil degradation. *Sustainability*. 2015;7:5875-5895.
33. Lal R, *et al*. Carbon sequestration potential of agroforestry systems. *Mitigation and Adaptation Strategies for Global Change*. 2018;23:1-25.
34. Leakey RRB. Multifunctional agriculture: Achieving sustainable development in Africa. *Current Opinion in Environmental Sustainability*. 2017;29:115-121.
35. Mall RK, Singh R, Gupta A, Srinivasan G, Rathore LS. Climate change and agriculture in India: Impacts and adaptation. *Agricultural Research*. 2018;7:257-270.
36. Montagnini F, Nair PKR. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agroforestry Systems*. 2012;61:281-295.
37. Nair PKR. An introduction to agroforestry. Dordrecht: Kluwer Academic Publishers; 1993.
38. Nair PKR. Carbon sequestration studies in agroforestry systems: A reality check. *Agroforestry Systems*. 2011;86:243-253.^[33]
39. Palm CA, *et al*. Conservation agriculture and ecosystem services. *Agriculture, Ecosystems & Environment*. 2014;187:87-105.
40. Pandey DN. Multifunctional agroforestry systems in India. *Current Science*. 2007;92(4):455-463.
41. Pandey R. Agroforestry systems in India: An overview. *Indian Journal of Agroforestry*. 2007;9(1):1-10.
42. Pingali P, Aiyar A, Abraham M, Rahman A. Transforming food systems for a rising India. New York: Palgrave Macmillan; 2019.
43. Ramakrishnan PS. Shifting agriculture and sustainable development. Paris: UNESCO; 1992.
44. Rao MR, Nair PKR, Ong CK. Biophysical interactions in tropical agroforestry systems. *Agroforestry Systems*. 2012;38:3-50.
45. Rizvi RH, Pandey A, Singh KP. Home gardens of India: A repository of plant diversity and cultural heritage. *Journal of Applied Horticulture*. 2017;19(2):73-81.
46. Singh G, *et al*. Economic analysis of poplar-based agroforestry systems in north India. *Agroforestry Systems*. 2017;91:631-643.
47. Singh K, Kumar R, Verma A. Nutritional security through homestead agroforestry in India. *Indian Journal of Ecology*. 2020;47(1):45-54.
48. Tandon HLS. Nutrient management for sustainable agriculture. New Delhi: FDCO; 2013.
49. Tewari S, *et al*. Agroforestry systems for climate resilience and livelihood security. *Journal of Environmental Management*. 2019;231:280-289.
50. Udawatta RP, Kremer RJ, Jose S. Agroforestry practices for soil and water conservation in India. *Soil and Tillage Research*. 2019;192:21-31.
51. Young A. Agroforestry for soil management. Wallingford: CAB International; 1997.