

Seeding resilience: Agroforestry's journey

from research to climate action

A. Arunachalam*, Suresh Ramanan S. and A. K. Handa

ICAR-Central Agroforestry Research Institute, Jhansi, Uttar Pradesh 284 003

Agroforestry as a distinct scientific field took root in the 1970s. Initially an emerging concept, it gained serious recognition in the last decade as global organisations such as the IPCC began highlighting its ecological importance. Today, agroforestry enjoys worldwide attention—not only for its ability to boost farm income, but also for its multiple cross-sector benefits, from supporting livestock and pastoralism to strengthening climate resilience in farming systems.

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MANY people assume agroforestry is simply the practice of combining agriculture with forestry, but in reality, it is much broader, more systematic, and interdisciplinary. Agroforestry deliberately integrates trees, shrubs, palms, bamboos, and other woody perennials with crops and/or livestock. This integration may occur side by side in space or sequentially over time. The interactions between these components are both ecological and economic, making agroforestry a unique blend of productivity, sustainability, and environmental care. Over time, the technical phrase “woody perennials” has been replaced by the more familiar term “trees,” which sometimes led to the misconception that agroforestry is forestry-dominated. In truth, it is a field that draws knowledge from agriculture, forestry, ecology, economics, and social sciences. The FAO even places agroforestry within the category of “Trees Outside Forests” in its Global Forest Resource Assessment.

In India, agroforestry is often confused with related but distinct practices such as farm forestry and social forestry. Farm forestry typically means cultivating trees in blocks on private farmland for timber, fuel, or other products. Social forestry, introduced in India in 1968 by the British forest expert Jack Westoby, focuses on community benefits like providing fuelwood, fodder, and recreation mostly on community or government lands. Agroforestry, however, is different: It is flexible, farmer-centered, and designed to provide both quick economic returns and long-term ecological services.

As agroforestry research advanced, another land-use concept began to emerge—Integrated Farming Systems (IFS). Because both approaches promote diversification, they are sometimes compared or even

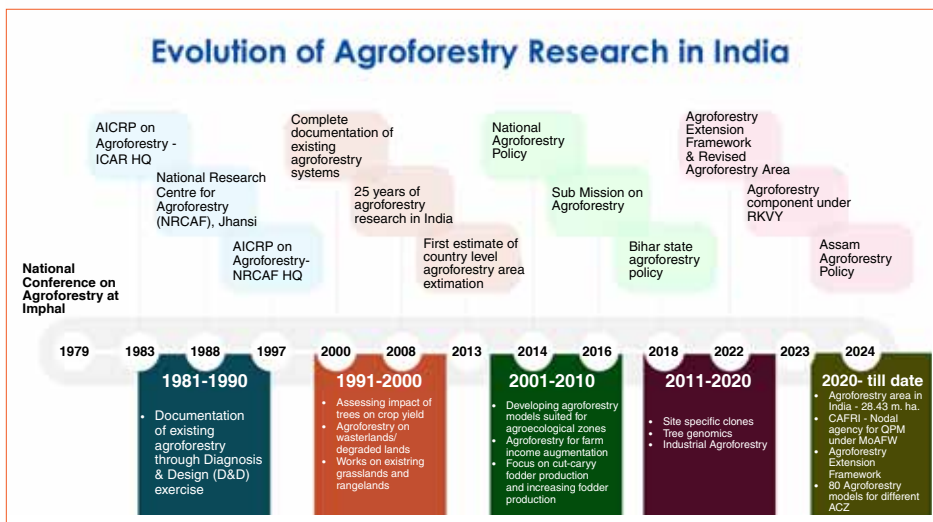
mistaken as similar. Yet, their design and focus differ. Agroforestry integrates trees with crops (sometimes also livestock or fish), whereas IFS links three or more independent enterprises such as crop cultivation, dairy, poultry, or fisheries on the same farm. In IFS, the units work largely on their own, with outputs harvested at different times, and the system often provides quicker cash flow. However, it is more labour-intensive, requires greater technical expertise, and depends heavily on reliable market access.

Agroforestry, in contrast, can be practiced by farmers across scales smallholders to large landowners and requires specialised labour only at certain stages. It also allows innovative combinations like aquaforestry (trees + crops + fisheries) and tree-based beekeeping (trees + crops + apiculture). Its multi-layered vegetation structure promotes vertical use of space, thereby enhancing biomass production and yield efficiency.

From the standpoint of inputs, agroforestry systems generally depend less on synthetic fertilisers, helping reduce costs while lowering environmental damage. IFS, due to its interdependence, is more vulnerable—failure in one enterprise can disrupt others. Agroforestry, by contrast, has relatively independent components that are managed to provide complementary benefits, making it more resilient in the long term.

The roots of agroforestry research

The formal recognition of agroforestry as a scientific field began in 1977, when Canada's International Development Research Centre (IDRC) and the FAO initiated the establishment of the International Centre for Research in Agroforestry (now known as the World Agroforestry Centre). Although its role in temperate



such as easing timber transit rules for farm-grown trees and the 2017 reclassification of bamboo under the Indian Forest Act (1927) have created new opportunities for cultivation. Initiatives like *Har Med Par Ped* (a tree on every field bund) and funding under the National Mission for Sustainable Agriculture have further incentivized farmers. At the global level, agroforestry has been mainstreamed into climate discussions, with research institutions highlighting its role in resilience building.

regions was initially debated, India quickly embraced the concept. Following a national seminar organized by ICAR in 1979, the All India Coordinated Research Project on Agroforestry was launched in 1983. The decade from 1977 to 1987 is often described as the formative period for agroforestry worldwide, and during the same years, India firmly institutionalized the discipline. This progression is captured in what can be termed the Agroforestry Research Roadmap.

From research to climate action

What began as farmer-led practices later refined by science has evolved into a central pillar of sustainable agriculture. Agroforestry now contributes multiple benefits—providing food, fodder, fibre, and fuel—while also enhancing soils, improving biodiversity, and capturing carbon. Its unique ability to increase farm productivity and conserve natural resources positions it as a key climate-smart solution, helping build resilience for future generations.

Although trees on farms are not new to India, what has changed in recent decades is the strategic and scientific approach to integrating them. Agroforestry has moved beyond being a traditional practice to being recognized as a climate action tool supported by research, policy, and technology. A landmark step was the adoption of the National Agroforestry Policy, which streamlined farmer participation. Regulatory reforms

Agroforestry and climate change mitigation

The IPCC has acknowledged agroforestry as a land-use strategy with high potential for carbon sequestration. Beyond stabilizing crop yields, it reduces soil erosion, provides fuelwood and construction material, and lessens the dependency on natural forests. In shifting cultivation systems, one hectare of well-managed agroforestry can replace 5–10 hectares of slash-and-burn land. Since systematic research began in the 1970s, its value as a climate strategy has been consistently recognized.

Climate mitigation through trees on farms can be pursued either by conserving existing tree cover or by planting fast-growing, short-rotation species on agricultural lands. Because agroforestry systems combine economic viability with environmental functions, they offer farmers both immediate benefits and long-term adaptation to climate change. Their design—where trees, crops, pastures, and soils interact—maximizes carbon storage and improves microclimates. Additional benefits include maintaining soil fertility, diversifying farm outputs, conserving water, and even strengthening gender equity in rural livelihoods. Two major mitigation mechanisms are involved: Sequestration of CO₂ and reduction of greenhouse gas (GHG) emissions. Evidence from around the world supports these claims. For example:

- In the Peruvian Amazon, nitrous oxide emissions



Mulberry based silvi-pastoral systems



Coconut based horti-pastoral system



Litsea based agri-silvicultural system



Ailanthus based agri-silvicultural

from peach-palm-based agroforestry were three times lower than high-input monocropping systems.

- In Rajasthan, arid agroforestry sequestered 0.26 Mg C/ha/yr at a density of 9.71 trees/ha reducing GHG emissions by 1.42 million tonnes annually.
- In central Alberta, Canada, nitrous oxide emissions under agroforestry were 89% lower compared to conventional croplands.
- In subtropical China, agroforestry systems emitted only 70% of the CO₂ produced by high-input systems, though methane release was slightly higher compared to low-input farms.

Evidence from Indian agroforestry

Studies from Sultanpur, Dinajpur, and Ludhiana districts reported that baseline standing tree biomass ranged from 2.45–2.88 Mg DM/ha, with total tree-crop biomass between 11.14–25.97 Mg DM ha. Soil organic carbon initially recorded at 8.13–9.12 Mg C/ha is projected to rise to 8.63–24.51 Mg C/ha over time. Long-term simulations estimated carbon sequestration potential at 0.111, 0.126, and 0.551 Mg C/ha/yr for Sultanpur, Dinajpur, and Ludhiana, respectively. For the Indo-Gangetic plains as a whole, the potential has been estimated at 36.25 t C/ha.

Potential agroforestry models for India

The ICAR-Central Agroforestry Research Institute (CAFRI) has developed region-specific models suited for different agro-ecological zones. Economic analysis shows that the benefit–cost (B:C) ratios of these models typically range from 1.3–2.5.



Teak based agri-silvicultural system

- ***Melia dubia* based systems:** These are commercially viable and compatible with a wide array of intercrops, including medicinal plants.
- ***Ailanthus excels* based systems:** Six-year-old plantations intercropped with cowpea, cluster bean, and green gram yielded 65.4 kg/ha, 195 kg/ha, and 199 kg/ha, respectively with B:C ratios between 2.4–3.1.
- ***Ardu (Ailanthus) in rainfed conditions:*** Net income varied from ₹55,824–₹76,024/ha, with the highest return recorded when intercropped with green gram. Given its 9–10-year rotation cycle and fodder value, this system outperformed sole cropping.
- ***Khejri based models in Rajasthan:*** These have proven highly resilient and profitable under arid conditions.

In addition, perennial tree-crop combinations are recommended for rehabilitating degraded lands. For example, tamarind-based silvi-horticultural systems have shown promise in Karnataka for land reclamation.

Table 1. Agroforestry models for different agro-ecological regions in India

Agro-ecological regions	Important AFS	Recommended intercrops
Western Himalaya (Cold-arid)	Mulberry based silvi-pastoral systems	Napier-bajra hybrid, <i>Setaria anceps</i>
Western Plain, Kutch and part of Kathiwar peninsula (Hot Arid)	<i>Melia azedarach</i> based agri-silvicultural system	Fox-tail millet
Deccan Plateau (400–500 mm rainfall)	<i>Melia dubia</i> based agri-silvicultural system	Finger millet and cowpea
Northern Plains and Central highlands including Aravallis	a) <i>Ailanthus</i> based agri-silvicultural system (Rainfed condition) b) Shisham based agri-silvicultural system and silvi-pastoral systems c) Aonla based agri-horticultural system	a) Cluster bean, cow pea and green gram b) Wheat, barley, lentil (Rabi) and green gram, black gram, sesame and Napier for Silvo-pastoral system c) Green gram, black gram and sesame (Kharif) and mustard, chickpea (Rabi)

Agro-ecological regions	Important AFS	Recommended intercrops
Central Highlands, Gujarat plains and Kathiwar peninsula	a) <i>Melia azedarach</i> based agri-silvicultural system	Soybean (JS-335)
Deccan Plateau (600–1000 mm rainfall)	a) Three tier agroforestry system for paddy growing area b) Teak based agri-silvicultural system c) Sapota based agri-horticultural system (hill zone of Karnataka) d) Tamarind based agri-silvicultural system for degraded lands e) Tamarind based silvi-horticultural systems	a) Paddy (<i>Kharif</i>) and black gram, lin seed (<i>Rabi</i>) b) Sorghum and groundnut c) Paddy and maize d) Fodder grass e) Curry leaves
Deccan Plateau (Telangana and Eastern plains)	a) <i>Terminalia</i> based agri-silvicultural system b) Tamarind based agri-silvicultural system c) Mango based agri-horticultural system	a) Aloe vera b) Henna c) Sorghum, safflower and cowpea
Eastern ghats, Tamil Nadu uplands, Deccan Plateau	a) <i>Melia dubia</i> based agroforestry system c) Coconut based horti-pastoral system	a) Black gram, green gram and red gram b) Cumbu Napier Hybrid
Northern Plains	Poplar based agri-silvicultural system	Mentha, moongbean, maize, sorghum, colocasia (<i>Kharif</i>) and wheat, mustard, potato (<i>Rabi</i>)
Central Highlands	Bamboo based agri-silvicultural system	Green gram, Black gram, sesame (<i>Kharif</i>) and mustard, chickpea and barley (<i>Rabi</i>)
Eastern Plateau (Chhattisgarh)	<i>Gmelina</i> and <i>Eucalyptus</i> based agri-silvi-horticultural system	Mustard, linseed, lentil, okra, bottle gourd
Eastern (Chotta Nagpur) Plateau and Eastern Ghats	Mango based agri-horticultural system	Mango ginger, turmeric and arrow root
Eastern Plain	<i>Dalbergia sissoo</i> based agri-silvicultural system	Ginger, turmeric and arrow root
Western Himalayas	<i>Grewia</i> based agri-silvicultural system	<i>Setaria anceps</i> and fodder
Bengal and Assam plains	a) <i>Litsea</i> based agri-silvicultural system b) <i>Dysoxylum</i> and Kadamb based agri-silvi-horticultural system c) <i>Bambusa balcoona</i> based agri-silvi-horticultural system	a) Bean, groundnut and legume crops b) Rice, mustard, lentil, cabbage, cauliflower, bottlegourd c) Banana, ginger, turmeric

Agro-ecological regions	Important AFS	Recommended intercrops
Eastern Himalaya	Agar based agroforestry system	Vegetables, pulses, fruits
North Eastern Hills (Purvanchal)	Alder based agri-silvi-horticultural system	Tea, coffee, maize, rice, ginger, potato, chilli
Eastern coastal plain	a) <i>Gliricidia sepium</i> and <i>Leucaena leucocephala</i> based silvi-pastoral system b) Guava with <i>Cenchrus ciliaris</i> based horti-pastoral system for degraded lands c) <i>Acacia mangium</i> based agri-silvicultural system	a) <i>Stylosanthus scabra</i> b) <i>Cenchrus ciliaris</i> c) Mango ginger, turmeric, and arrow root
Western Ghats and Coastal plains	a) Bamboo based agri-silvicultural system b) Jackfruit and acacia based silvi-horticultural system c) Mulberry and calliandra based silvi-pastoral system	a) Mango ginger, turmeric and arrow root b) Ginger c) Finger millet and proso millet
Islands of Andaman-Nicobar and Lakshadweep	a) Coconut based horti-pastoral system	a) Black pepper and fodder grass

SUMMARY

Over the last fifty years, agroforestry has progressed from being a traditional, farmer-driven practice to a science-backed and policy-supported solution for sustainable agriculture and climate resilience. In India, this transformation has been accelerated through dedicated research, technological innovations, and enabling policies such as the National Agroforestry Policy, simplified tree transit regulations, and state-level agroforestry initiatives. By integrating trees with crops, livestock, and other enterprises, agroforestry enhances farm productivity, diversifies income streams, restores degraded lands, and lowers environmental impacts. Its contribution to climate change mitigation is especially significant, with proven potential for carbon sequestration and reductions in greenhouse gas emissions. The development of region-specific models by ICAR-CAFRI demonstrates agroforestry's adaptability across India's diverse agro-ecological zones, making it relevant and beneficial to farmers of all scales. With both immediate economic gains and long-term ecological benefits, agroforestry represents a future-ready farming pathway. As global and national agendas increasingly align around sustainability and climate action, agroforestry stands out as a practical, scalable, and resilient land-use system that balances livelihood security with environmental stewardship.

*Corresponding author email: arun70@gmail.com