

Agroforestry for improving livelihood security and climate resilience in northeast India

Nongmaithem Raju Singh^{1*}, Bidyapati Thangjam¹, P. L. Bhutia², P. K. Sarkar³, M. Prabha Devi¹, S. Hazarika¹ and V. K. Mishra¹

¹ICAR Research Complex for North Eastern Hill Region, Umiam, Meghalaya 793 103

²ICAR Research Complex for North Eastern Hill Region, Nagaland Centre, Medziphema, Nagaland 797 106

³ICAR Research Complex for North Eastern Hill Region, Tripura Centre, Lembucherra, Tripura 799 210

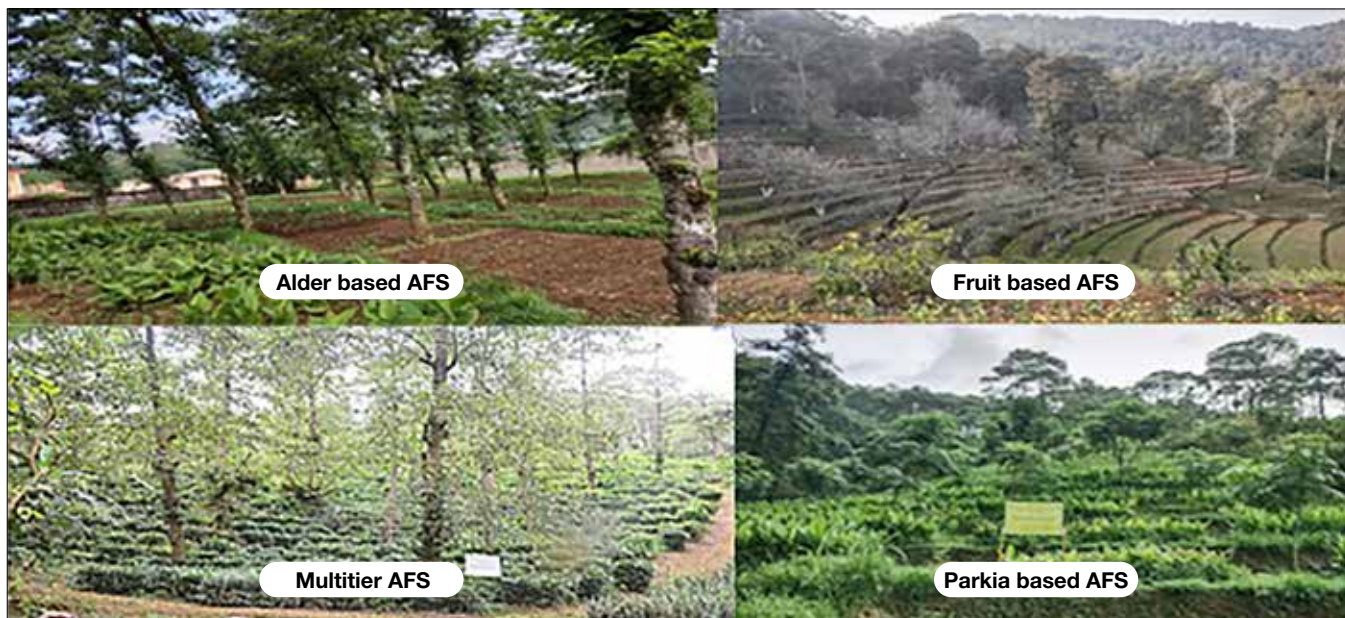
Agroforestry is a sustainable land-use practice combining agriculture and forestry to foster ecological, economic, and social benefits. In India, where 70% of the rural population consists of smallholder farmers, agroforestry plays a vital role in reducing pressures on natural forests while providing diversified income and improving climate resilience. Particularly in Northeast India, agroforestry has been integrated into traditional farming systems for centuries, offering solutions to land degradation, reduced agricultural productivity, and climate change adaptation. Diverse agroforestry systems practiced in the north eastern states provide valuable resources like timber, fruits, fodder, and medicinal plants. Furthermore, agroforestry contributes to rural socio-economic development, food security, and poverty alleviation. As climate change poses growing challenges, agroforestry offers a promising path toward sustainable livelihoods and enhanced environmental resilience in India, particularly for marginalized farming communities.

Keywords: Climate resilience, Land degradation, Sustainable livelihoods

IN India 70% of the total population belongs to marginal and small farmers, which are complementing the agricultural deficits from the forest resources, leading to qualitative and quantitative deteriorations in forest. Agroforestry contributes over 65% of India's timber needs, reducing the pressure on natural forests. States like Uttar Pradesh, Haryana, and Punjab are leading in agroforestry practices, supported by government subsidies and corporate partnerships. In this context, agroforestry emerges as a promising approach to enhance climate resilience and foster sustainable livelihoods for the country. The key idea behind agroforestry is symbiotic land-use practice that combines agriculture and forestry, has become a crucial tool in India's fight against climate change, rural poverty, and environmental degradation. This holistic approach integrates trees and shrubs into farmlands, offering ecological, economic, and social benefits. Agroforestry is more than just planting trees, it is a sustainable pathway towards improving agricultural productivity, enhancing biodiversity, and ensuring environmental resilience.

Approximately 25 million hectares of farmland in India is under agroforestry, contributing significantly to the economy and environment. This system of land use provides multiple ecosystem services such as improving soil fertility, enhancing biodiversity, conserving water, and sequestering carbon. Climate resilience and sustainability are essential for the future of agriculture, requiring practices that reduce environmental impact, such as lowering water usage and greenhouse gas emissions, while boosting resilience to climate shocks.

Northeast India, with a diverse range of climatic conditions, is highly vulnerable to changing weather patterns, which affects agricultural productivity, water resources, and local communities' livelihoods. Northeast states have a long history of traditional farming systems, with indigenous communities practicing agroforestry for centuries. These traditional systems are deeply rooted in the region's cultural and ecological landscapes. In particular, systems like shifting cultivation, home gardens, and mixed cropping have incorporated trees and other perennial vegetation alongside crops, ensuring



Some of the prominent AFS of northeast India

sustainable use of land and resources. However, rapid urbanization, population growth, and changes in land use have placed increasing pressure on the environment. In recent decades, traditional agroforestry practices have been disrupted, leading to land degradation, loss of biodiversity, and reduced resilience to climate change. This has resulted in lower agricultural yields and economic instability for farmers in the region. Agroforestry might be the best land-use system for sustainable livelihood in north-eastern states to cope with the present situation. It is a land based production system that is directly related to food security, employment, income opportunities and environmental issues.

Agroforestry for developing sustainable land use in northeast India

The region's economy is predominantly agrarian, with around 75% of the population relying on agriculture and related activities. However, traditional farming practices and an over-reliance on mono-cropping have resulted in declining soil fertility and heightened vulnerability to climate change. Some of the major challenges include:

- Heavy dependence on rainfed agriculture, leading to seasonal food insecurity
- Soil degradation caused by shifting cultivation, reducing productivity
- Deforestation, contributing to biodiversity loss and increased carbon emissions
- Increased frequency of floods and landslides, exacerbated by deforestation and climate change
- Limited access to modern agricultural technologies and financial resources
- Agroforestry, which integrates trees with crops and livestock, presents a promising solution. It enhances ecosystem services, boosts soil fertility, and provides farmers with diversified income opportunities, helping to address these pressing challenges while promoting environmental sustainability.

Agroforestry systems in the context of northeast India

In North Eastern Hill (NEH) region of India, agroforestry is an important agricultural practice, as it helps to conserve the region's fragile ecosystem and improve the livelihoods of local farmers. The NEH region of India is known for its diverse and challenging terrain, and this region has long tradition to several unique agroforestry systems (AFS). For instance, alder based AFS in Sikkim and Nagaland, arecanut with pineapple and black pepper in the mild tropical and plain region, khasi mandarin based AFS in Meghalaya, home gardens in Assam and Manipur plains, and Parkia based AFS across the region. These systems help to optimize several ecosystem functions including both tangible and intangible services. In other words, agroforestry practices, which blend crops, trees, and animals, are widely adopted across different regions of northeast India. These practices not only help boost agricultural productivity but also enhance the adoption of agroforestry among farmers.

Agroforestry for livelihood security

Agroforestry plays a pivotal role in promoting sustainable agriculture, improving livelihoods, and supporting climate resilience. Agroforestry practices traditionally provided interdependent benefits from trees, crops, and livestock, contributing to sustainability through the 6Fs: Food, Fruit, Fodder, Fuel, Fertilizer, and Fiber. These diversified systems integrate a variety of crops, trees, and livestock, enhancing soil fertility, reducing pest risks, and improving biodiversity. The selection of tree species and intercrops depends on the region's climate and the economic value of the species. Nitrogen-fixing trees like Alder improve soil health, while bamboo, a valuable non-timber resource, provides economic benefits. These systems offer farmers a steady income through crops such as fruits, vegetables, and timber, while also supporting food security by growing a variety of crops. Livelihoods are further bolstered

by the cultivation of high-value crops such as ginger, turmeric, and cardamom, as well as fruit trees like mango and betel nut, which have significant cultural and economic value. The integration of agroforestry with fish farming boosts productivity and ensures sustainable land use. In AFS, trees also enhance livestock

production by providing shade, fodder, and shelter, improving animal health and productivity, especially in regions with harsh climates. The findings of the earlier studies conducted in this region revealed that in tropical hill and plain areas, a combination of pineapple, black pepper, and arecanut generates a net return of

Table 1. Prominent improved agroforestry systems of northeast India

State	Agroforestry System	Key Tree Species	Crops Integrated
Nagaland	Agri-silvicultural system	<i>Alnus nepalensis</i> , Bamboo	Rice, Maize, Potatoes, Ginger, Turmeric, Mustard
	Agri-horticultural system	<i>Areca catechu</i> , <i>Citrus</i> spp, <i>Amomum subulatum</i>	Ginger, Turmeric, Mustard, Pineapple, Vegetables
	Silvi-pastoral system	<i>Leuceana leucocephala</i> , <i>Sesbania grandiflora</i> , <i>Gliricidia sepium</i> , <i>Azadirachta indica</i> , <i>Morus alba</i>	Fodder Grasses
Meghalaya	Agri-silvicultural-pastoral system	<i>Alnus nepalensis</i> , <i>Parkia timoriana</i> , <i>Michelia champaca</i> , <i>Gmelina arborea</i> , <i>Schima wallichii</i> , <i>Pinus kesiya</i> , <i>Morus alba</i>	Ginger, Turmeric, Soybean, Rice Bean, Groundnut, Tiger Grass, Guinea Grass
	Horti-silvicultural system	<i>Alnus nepalensis</i> , <i>Grevillea robusta</i> , <i>Psidium guajava</i>	Pineapple, Black Pepper
	Agri-horti-pastoral system	<i>Citrus reticulata</i> , <i>Psidium guajava</i> , <i>Citrus reticulata</i>	Tiger Grass, Guinea Grass, Broom Grass
	Agri-horticultural system	<i>Citrus reticulata</i> , <i>Citrus limon</i> , <i>Psidium guajava</i> , <i>Prunus persica</i> , <i>Pyrus</i> spp	Ginger, Turmeric, Soybean, Pea
Arunachal Pradesh	Agri-Horti-Silvicultural System (Nyishi Community)	<i>Gliricidia sepium</i> , <i>Pinus wallichiana</i> , <i>Alnus nepalensis</i> , <i>Bamboo</i> spp	Finger Millet, Maize, Cassava, Yam, Chili, Potato, Eggplant, Taro, Betel Vine, Ginger.
	Bamboo-Based Silvicultural System (Apatani Community)	<i>Bamboo</i> spp, <i>Pinus wallichiana</i>	Vegetables
	Toko-Based Agroforestry (Adi Tribes)	<i>Livistona jenkinsiana</i> , <i>Citrus</i> spp	Ginger, Maize, Ragi, Tubers, Vegetables
Tripura	Agri-Silvicultural System	<i>Tectona grandis</i> , <i>Acacia auriculiformis</i> , <i>Gmelina arborea</i>	Upland Rice, Vegetables
	Silvi-Horticultural System	<i>Tectona grandis</i> , <i>Gmelina arborea</i> , <i>Azadirachta indica</i>	Pineapple, Ginger, Black Pepper, Banana,
	Waterlogged Agroforestry	<i>Areca catechu</i> , <i>Cocos nucifera</i> , <i>Artocarpus heterophyllus</i>	Wetland Crops (<i>Colocasia</i> , <i>Esculenta</i>), Ginger
	Silvi-pastoral system	<i>Tectona grandis</i> , <i>Gmelina arborea</i>	Fodder Grasses
Assam	Aqua based agroforestry system	<i>Artocarpus heterophyllus</i> , <i>Mangifera indica</i> , <i>Citrus</i> spp, <i>Cocos nucifera</i> , <i>Areca catechu</i>	Rice, Maize, Vegetables Pineapple, Banana
	Homestead/homegarden	<i>Artocarpus heterophyllus</i> , <i>Mangifera indica</i> , <i>Citrus</i> spp, <i>Zizyphus mauritiana</i> , <i>Cocos nucifera</i> , <i>Areca catechu</i> , <i>Dillenia indica</i> , <i>Citrus Limon</i>	Vegetables, Rice ,Maize, Banana
	Agri-silvicultural system	<i>Acacia mangium</i> , <i>Michelia Champaca</i> , <i>Gmelina arborea</i> , <i>Tectona grandis</i>	Upland Rice, Maize, Vegetables
Mizoram	Home Gardens	<i>Parkia roxburghii</i> , banana, papaya, bamboo, citrus, guava	Tuber crops, vegetables, pineapple, livestock (pigs, poultry)
	Agri-silvi-horticultural	Teak, Subabul, Pigeon pea, Lemon	Paddy, fodder
	Agri-silvicultural	<i>Aleurites fordii</i> , <i>A. montane</i> , <i>Alnus nepalensis</i> , <i>Azadirachta indica</i> , <i>Gmelina arborea</i> , <i>Michelia champaca</i> , <i>Schima wallichii</i> , <i>Parkia timoriana</i>	Maize, turmeric, ginger, chillies
	Horti-silvicultural System	Teak, <i>Bauhinia</i> , Subabul	Pineapple, orange, guava, mango
	Bamboo and cane-based System	<i>Melocanna baccifera</i> , <i>Dendrocalamus strictus</i> , <i>Bambusa tulda</i>	Ginger, turmeric, soybean, mustard
	Coffee-based System	<i>Gmelina arborea</i> , <i>Schima wallichii</i> , <i>Michelia champaca</i> , <i>Toona ciliata</i> , <i>Bauhinia</i> spp.	Coffee

State	Agroforestry System	Key Tree Species	Crops Integrated
Manipur	Silvi-Pastoral System	<i>Albizia</i> spp., <i>Alnus nepalensis</i> , <i>Schima wallichii</i> , <i>Parkia roxburghii</i> , <i>Gmelina arborea</i> , <i>Quercus</i> spp.	Elephant grass, Desho grass, Teosinte, Changing
	Agri-Silvi-Pastoral System	<i>Litsea polyantha</i> , <i>Ficus</i> spp., <i>Alnus nepalensis</i> , <i>Bauhinia</i> spp., <i>Erythrina indica</i> , <i>E. suberosa</i>	Maize, Pigeon pea, Cowpea, Fodder grasses
	Agri-Horti-Pastoral System	<i>Parkia roxburghii</i> , <i>Elaeocarpus serratus</i> , <i>Phyllanthus emblica</i> ,	Fruit trees, Vegetables, Fodder grasses
	Homegarden	<i>Clerodendrum colebrookeanum</i> , <i>Bambusa nutans</i> , <i>Hedychium flavum</i> , <i>Oroxylum indicum</i> , <i>Parkia timoriana</i> , <i>Zanthoxylum acanthopodium</i> , <i>Ziziphus jujuba</i> , <i>Mangifera indica</i> , <i>Psidium guajava</i>	Seasonal vegetables/crops, fodder grasses, fruit trees
Sikkim	Agri-silvicultural system	<i>Bamboo</i> , <i>Pine</i> , <i>Oak</i> , <i>Alder</i> , and other local species.	Rice, Maize, Millet, Pulses, Vegetables
	Cardamom-based Agroforestry	<i>Alnus nepalensis</i> , <i>Areca catechu</i>	Cardamom, Spices, Vegetables
	Agri-horticultural	Sikkim mandarin, <i>Citrus reticulata</i> , <i>Persea americana</i>	Maize, ginger, turmeric, vegetables, pulses, flowers
	Agri-horti-silvi-pastoral	<i>Citrus reticulata</i> , <i>Persea americana</i> , <i>Juglans regia</i> , <i>Ficus</i> sp., <i>Schima wallichii</i>	Maize, ginger, vegetables, oilseeds, pulses
	Homesteads	<i>Citrus reticulata</i> , <i>Citrus</i> spp, <i>Punica granatum</i> , <i>Moringa</i> , <i>Mangifera</i>	Vegetables, floriculture, fishery, mushroom, livestock

₹43,000/ha. Similarly, in temperate zones, plum with potato or cole crops yields ₹19,000/ha. Mandarin trees, when optimally planted at 400 per hectare, show significant yield growth, from 12.8 kg/tree after 7 years to 57.3 kg/tree after 12 years. Between these trees, crops like groundnut, soybean, turmeric, ginger, and local taro can be grown for additional income. The studies conducted in *Parkia roxburghii* based AFS provided a yield of ₹ 1,854/tree and farmers could earn a total of ₹ 3.609 lakh/ha. Three-tier agroforestry systems with alder, tea, and crops like large cardamom, ginger, and black pepper generates a net benefit of ₹ 33,111/ha.

Carbon sequestration potential of AFS

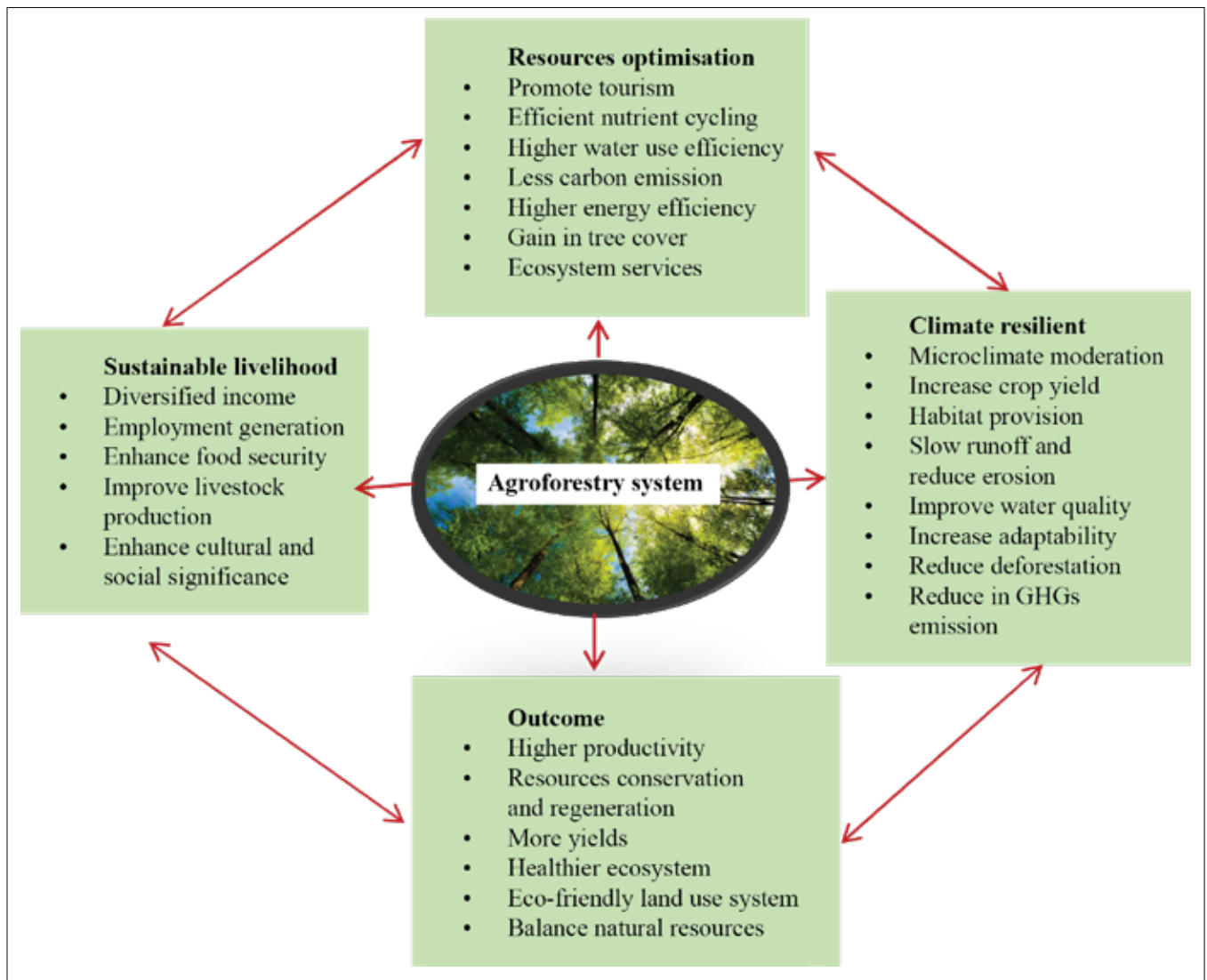
The key feature of AFS is their significant contribution to carbon sequestration, a key strategy in addressing climate change. The trees within these systems act as efficient carbon sinks, capturing and storing carbon dioxide from the atmosphere. This dual function not only reduces the carbon footprint of agricultural practices but also aligns with global climate action efforts. As the trees grow, they sequester carbon in both their biomass and the soil, effectively serving as a natural reservoir for greenhouse gases. This approach highlights the synergy between agriculture and climate solutions, demonstrating how agroforestry can play a pivotal role in mitigating climate change and fostering environmental resilience.

Recent studies have shown that AFS can sequester carbon at rates that are much higher than those of monoculture cropping systems or natural forests. For instance, AFSs in the tropics can sequester carbon at rates of up to 20 tonnes of CO₂/ha/yr, while monoculture cropping systems typically sequester less than 1 tonne of CO₂/ha/yr. Another study in the temperate regions

revealed that AFS can sequester carbon at rates of up to 10 tonnes of CO₂/ha/yr, while natural forests in the same region sequester around 5 tonnes of CO₂/ha/yr. Similarly, one of the studies conducted in north-eastern part of India estimated that AFS has the capacity to store carbon at rates of up to 15 tonnes of CO₂/ha/yr. Other studies conducted in this region found that the *P. roxburghii* based AFS have the carbon sequestration potential of about 0.23 Mg/ha/yr, suggesting as an important tree component (carbon sink) while restoring the degraded jhum lands of the region. Overall, this data clearly shows that agroforestry has a high potential for carbon sequestration, which will eventually help in reducing the CO₂ concentration of the atmosphere.

Agroforestry for soil improvement

The continuous accumulation of leaf litter and its decomposition in AFS enhance nutrient availability for intercrops by enriching soil fertility, promoting better nutrient uptake, and optimizing nutrient cycling processes. The research conducted in 26 years old *Parkia*-based AFS in Meghalaya revealed that this system produced 415.50 g/m² of root biomass and 353.92 ± 14.40 g/m² of annual litter biomass, thereby adding continuous carbon to the system. Similar results have been reported from AFSs of the NEH region of India where AFS produced have a substantial positive impact on soil quality by enhancing soil organic matter, soil structure, and soil fertility. A study conducted in the state of Meghalaya discovered that agroforestry systems elevated soil organic matter by as much as 40% in comparison to monoculture cropping systems. The study also found that these systems improved soil structure and fertility, resulting in higher crop yields. Another study in Meghalaya found that agroforestry



systems positively impacted soil quality by increasing soil organic matter, total nitrogen, and available phosphorous, as well as positively influencing the microbial population of the soil and increasing its capacity to retain water. These studies provide evidence that agroforestry can significantly improve soil quality in the NEH region of India, thereby increasing the productivity and protecting the limited available natural resources for the generation to come. Another study conducted in NEH region of India also found that AFS can increase the availability of nutrients to crops by up to 50% and the efficiency of nutrient cycling by up to 30% in comparison to monoculture cropping systems. Research also indicated that water-stable aggregates (>0.25 mm) increase under various multipurpose tree species. By offering multiple benefits, agroforestry systems reduce economic vulnerability and increase the well-being of rural communities, especially by buffering against shocks like droughts, floods, or pests. Recent studies show that conventional farmers perceive climate change negatively impacting food security and health. In contrast, smallholder agroforestry farmers rely on trees for income from fruits, firewood, fodder, timber, and medicine. Trees help farmers manage risks by storing financial capital for emergencies.

Agroforestry for climate resilient

Agroforestry systems diversify income, improving farmers' resilience to extreme weather events. Additionally, trees and shrubs in agroforestry systems create habitats for pollinators, such as bees and butterflies, boosting the yields of pollinator-dependent crops. By providing shade and reducing soil temperature fluctuations, agroforestry systems create microclimates that help maintain moisture levels, which is particularly beneficial in areas with extreme temperatures. Trees on farms provide timber, fodder, and fuel wood, offering a safety net during climate shocks. In times of crop failure, farmers turn to trees for livestock feed, reducing vulnerability. Agroforestry systems substitute timber, fodder, and fuel wood demands, helping farmers cope with climate change and forest degradation. These systems reduce deforestation of protected forests and enhance local income resilience. One-third of a household's income comes from trees on farmland, which is less impacted by climate hazards like drought. Agroforestry plays a vital role in improving farmers' resilience to climate change. In regions prone to soil erosion, the root systems of trees slow water runoff, reduce erosion, and prevent the loss of topsoil, especially in hilly areas. Agroforestry also contributes to

improved water quality by filtering runoff, preventing contaminants from entering water sources, and promoting groundwater recharge.

SUMMARY

Agroforestry, integrating trees with crops and livestock, is a critical tool in addressing climate change, rural poverty, and environmental degradation in India. Agroforestry helps reduce pressure on natural forests by contributing over 65% of the country's timber needs. In northeast India, agroforestry has been a part of traditional farming systems for centuries, helping farmers cope with climate variability. These systems offer diverse benefits, such as improving soil fertility, conserving water, enhancing biodiversity, and

sequestering carbon. Specific agroforestry practices in states like Nagaland, Meghalaya, and Manipur involve the integration of nitrogen-fixing trees, fruit trees, and crops like maize, ginger, turmeric, and cardamom, boosting productivity and resilience. As climate change impacts food security and health, agroforestry offers a way to diversify income sources, reduce vulnerabilities, and buffer against extreme weather events. Agroforestry also holds cultural significance, preserving traditional knowledge and strengthening communities' connection to the land.

*Corresponding author email: rajuforestry@gmail.com

