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Multipurpose crop-based farm agroforestry. Photo: Ghanashyam Sharma

# Multipurpose, climate-resilient agroforestry in the Eastern Himalayas

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*"Agroforestry can improve the socio-ecological and socio-economic status of Indigenous populations and enhance mountain ecosystem services."*

## Introduction

Traditional farmers in various developing regions have passed down intricate farming systems that effectively manage challenging environments and climate variations while fulfilling subsistence requirements. These systems have been successful without relying on modern agricultural technologies such as mechanization, chemical fertilizers or pesticides. India's rich historical legacy of agroforestry practices continues to be acknowledged by contemporary ecologists and development agencies (Kumar and Sikka 2014).

India's National Research Centre for Agroforestry (NRCA) has conducted research that has contributed in many ways, such as identifying suitable tree species for the country's different agro-ecological zones. One of the outcomes of the 2014 World Congress in Agroforestry was the promulgation of Indian's National Agroforestry Policy.

**Forest-based agroforestry around cultivated farms. Photo: Ghanashyam Sharma**

The traditional farming systems in the Eastern Himalayas are a compelling example of small-scale agroforestry systems (including homegardens) that have been managed by Indigenous farmers for generations. These systems offer a range of socioecological, sociocultural and socioeconomic benefits. Their diverse array of multipurpose trees, shrubs, traditional crops and livestock (Sharma et al. 2016) promotes ecological sustainability. They are more diverse than monocropping, providing multiple services to households. The predominant land-use practices in the region include agroforests and other agroforestry systems, open cropped areas, and adjacent forests. This article discusses efforts to implement Indigenous agroforestry-based agricultural management in the Eastern Himalayan region.

## Agroforestry diversity

During the early 17th century, Nepali farmers initiated terrace farming practices in Sikkim. Subsequently, they devised a variety of agroforestry systems within Sikkim and extended towards Bhutan and the northeastern Himalayas. These innovations were later adopted by other mountain farmers in the region. Traditional agroforestry practices in the region are classified into seven systems: farm-based, forest-based, large cardamom-based (with two subsystems: alder-cardamom and mixed trees-cardamom), mandarin based, crops/mixed trees-based, slash-and burn based, and tea-garden-based (Table 1). These systems possess the potential to improve livelihoods by providing farmers with a range of alternatives to increase both farm production and income. Furthermore, they support productive and protective roles for ecosystems, including promoting biological diversity, maintaining healthy ecosystems, preserving soil and water resources, storing terrestrial carbon, and enhancing resilience.

### *Farm-based agroforestry*

In this system, farmers manage multipurpose tree species for fodder, firewood and timber within and around cultivable land, as well as in terrace risers to stabilize soil. They also practise intercropping under tree canopies (photo page 145). The system consists of *sukha-bari* (rainfed fields) with crops such as maize-potato and maize-ginger, as well as *pani-khet* (wet rice-based fields) where rice is followed by winter crops and vegetables. Effective management of fodder trees and food production is critical for maintaining livestock.

### *Forest-based agroforestry*

This system integrates forested and farmed areas (see photo above), including bamboo groves. Farmers cultivate multipurpose trees (with social, ecological, economic and aesthetic functions), and safeguard timber species for construction and repairs. To regulate water and prevent flooding, erosion and slope instability, agroforestry plots are situated along ridges and furrows, vertically on slopes, and horizontally between slopes. Downhill drainage offers consistent irrigation and the terraced slopes are shielded by agroforests.

### *Large cardamom-based agroforestry*

This system includes a diversity of multipurpose trees that include fodder trees and bushes, timber trees, fruit trees, etc. (see photo a, below). Large cardamom (*Amomum subulatum*) is a valuable cash crop cultivated in the northeastern states of India, Bhutan and Nepal between 600 and 2,300 metres above sea level (masl), in areas with mean annual rainfall of 1,500–3,500 mm. Its distinctive aroma and flavour make it highly sought after in the global market. Large cardamom production involves low volume per plant and requires relatively low labour inputs, which is advantageous for smallholder farmers.

#### Alder-cardamom agroforestry

Himalayan alder (*Alnus nepalensis*) is a naturally occurring tree that forms a beneficial association with cardamom, offering shade, nitrogen fixation and nutrient-rich litter (Sharma et al. 2008). This pioneer species thrives in challenging environments such as landslide soils, denuded habitats, rocky slopes, stream banks and natural areas. Farmers gradually establish an alder-cardamom association (see photo b, below) by planting cardamom saplings and maintaining tree density annually (Sharma et al. 2016). The system has economic viability, ecological adaptability, social acceptability, and considerable carbon sequestration potential (Sharma and Sharma 2017).

#### Mixed trees-cardamom agroforestry

Common shade trees used in large cardamom agroforestry systems include *Schima wallichii*, *Engelhardtia acerifolia, Eurya acuminata, Leucosceptrum canum, Maesa chisia, Symplocos theifolia, Ficus nemoralis, Ficus hookeri, Nyssa sessiliflora, Osbeckia paniculata, Viburnum cordifolium, Litsaea polyantha, Macaranga pustulata*, and *Alnus nepalensis* (see photo c, below). Large-cardamom agroforestry practices also conserve biodiversity elements in the region. This system promotes a more diverse range of tree species than other agroforestry systems in the


a


b


c

**Diverse agroforestry systems a) large cardamom agroforestry; b) alder-cardamom agroforestry; c) mixed trees-cardamom agroforestry.**
**Photos: Ghanashyam Sharma**

region. The trees also support birds and other wildlife, which contributes to the system's ecological structure and functioning.

### *Mandarin-based agroforestry*

This system (which also includes *Albizia stipulata* and other tree species) intercrops high-value cash crops, such as Sikkim mandarin (*Citrus reticulata*) and ginger with maize, pulses, buckwheat, finger millet, oilseeds, taro and yam on non-irrigated *sukha-bari* land (see photo a, below). Large cardamom cultivation is also included in this system. The system is promising at lower elevations (250–1,700 m). *Albizia*, another nitrogen-fixing species, is commonly grown alongside other trees in this system to enrich soil fertility.

### *Crop/mixed-trees-based agroforestry (>300 m)*

Riverbanks and terraced slopes contribute to the genetic diversity of traditional rice varieties, such as *krishna bhog*, *nuniya* and *kataka*. This agroforestry landscape (see photo b, below) demonstrates the importance of traditional ecological knowledge. Some dryland and wet-rice varieties have declined, while irrigated rice varieties, such as *attey*, *timmurey, jhapaka, bacchhi, mansaro, baghey-tulasi*, *champasari, sikrey* and *taprey*, are well-adapted to agroecological zones ranging from 300 to 1,800 m in elevation (Sharma and Sharma 2017). Tree-lined terraces protect upland rice cultivation, conserving water and providing nutrients.

Legumes, beans, maize, wheat, buckwheat, oilseeds and vegetables are cultivated during the winter. This agroforestry system also integrates large cardamom and forests, conserving water, controlling floods and providing nutrients and habitat for wild animals. The region supports agrobiodiversity, traditional irrigation practices, and diverse cropping systems. Numerous farmers practice agroforestry by allowing their animals to graze within these systems, while others opt for stall-feeding their livestock due to the scarcity of grazing areas within their agroforestry farms.

### *Slash-and-burn agroforestry*

The Lepcha Indigenous community in Sikkim has devised agroforestry systems tailored to both valleys and steep slopes. Employing a technique referred to as *bhashmey-kheti*, they practise shifting cultivation in the Dzongu valley (see photo a, next page). This slash-and-burn technique involves a series of steps: in December, a considerable forest expanse is cleared. The resulting debris is set ablaze as a means of generating fertilizer, a practice conducted from mid-February to mid-March. Following this, at the advent of the monsoon season, crops are sown. After one or two crop cycles, the land is left fallow, while new areas are prepared. This labour-intensive process involves all family members; men engage in physically demanding tasks and women handle debris clearance, seed selection, sowing and harvesting. Farmers maintain the cultivation of traditional varieties of cereals, pulses, oilseeds, tubers, and lesser-known underutilized crops,



**Diverse agroforestry systems a) Mandarin -based agroforestry; b) crop/mixed-trees based agroforestry. Photos: Ghanashyam Sharma**

with women playing a crucial role in safeguarding and preserving the seeds.

This method relies on the soil fertility of cleared forests to cultivate a diverse range of crops, encompassing dry paddy, wet paddy, maize, wheat, hulless barley, buckwheat, millet, grain amaranths, oat, sorghum, Job's tears (*Coix lachryma*), ginger, turmeric, legumes and pulses, *chayote* (*Sechium edule*), domesticated and wild yams (*Dioscorea* spp.), cassava, colocasia (*Colocasia esculenta*), and a variety of cucurbits. The Dzongu region currently has a solitary upland dry paddy (*tuk-mor-zho*), an ancient practice of the Lepcha people. They also cultivate mandarin oranges, peas, pear, plum, avocado and large cardamom, as well as wild edibles, encompassing medicinal and aromatic plants.

Until the early 2000s, shifting cultivation (*sudyom prek shyon* or *sudyom hong shyong*) was the predominant agricultural method practised by the Lepcha on the steep slopes of the Dzongu area. Echoes of this approach still persist in the upper reaches of Dzongu, where a diverse array of crops are cultivated.

### *Tea garden*

The Temi tea (*Camellia sinensis* L.) garden, established in 1969, encompasses an area of 176 hectares (ha) along steep hillsides ranging from 1,200 to 1,800 masl. This tea fetches a premium price in the international market. The first flush of Temi tea fetched record breaking price of INR 10,250 per kg (USD 124) in 2023. The garden is operated by the Government of Sikkim and produces approximately 100 metric tonnes of tea annually, which undergoes on-site processing and packaging. Recently, the tea garden has been certified as organic, leading to increased demand.

The Darjeeling Hills have a total area of 241,700 ha, of which an estimated 40% is covered by forests, 40% by *khasmal* (forests for community use) and municipalities, 2% by cinchona plantations, and 18% by tea plantations (see photo b, below). First planted in 1839, Darjeeling tea has a quality that is the result of climate, soil conditions, altitude and meticulous processing. About 10,000 metric tonnes are grown every year, spread over 17,500 ha of land. The tea has its own special aroma, a rare fragrance that fills the senses. Tea from Darjeeling has been savoured by connoisseurs all over the world. The first flush of this tea fetched around USD 278 per kg in 2023.

This integrated system offers ecological and economic advantages and promotes biodiversity conservation. It includes alley cropping (tea grown in between rows of woody/non-woody species), which benefits soil fertility, carbon sequestration and erosion control. Intercropping tea with ginger, turmeric or fruit trees diversifies income and improves pest management. Preserving natural habitats (streams, ponds, forests) within tea plantations promotes biodiversity and supports pollinators, birds and mammals.



**Diverse agroforestry systems a) agroforestry based on slash-and-burn; b) tea garden-based agroforestry system, Teesta Valley, Darjeeling. Photos: Ghanashyam Sharma**

**Table 1. Stand dynamics in seven agroforestry systems**

| Parameter | Agroforestry system | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1. Farm-based** | **2. Forest-based** | **3. Large cardamom-based** | **4. Mandarin based** | **5. Crop, mix-tree-based** | **6. Slash and burn-based** | **7. Tea-garden-based** |
| Tree density (trees $ha^{-1}$) | 198 ± 25 | 843 ± 132 | 417 ± 17 | 280 ± 54 | 723 ± 124 | 153 ± 34 | 78 ± 34 |
| Basal area ($m^2$ $ha^{-1}$) | 6.43 ± 1.21 | 21.36 ± 3.66 | 19.51 ± 3.43 | 5.10 ± 1.23 | 12.51 ± 1.49 | 3.87 ± 2.6 | 3.12 ± 0.5 |
| Tree biomass (t $ha^{-1}$) | 12.84 ± 2.54 | 59.45 ± 3.25 | 64.61 ± 5.81 | 15.21 ± 26 | 23.42 ± 4.53 | 10.32 ± 31 | 6.32 ± 42 |
| Net primary productivity (t $ha^{-1}$) | 4.65 ± 1.87 | 8.43 ± 2.39 | 12.61 ± 3.26 | 3.51 ± 1.26 | 5.13 ± 0.99 | 6.35 ± 24 | Not estimated |
| Agronomic yield of crops (t $ha^{-1}$ $year^{-1}$) | 1.14 ± 1.65 | 0.21 ± 0.04 | 0.31 ± 0.10 1 | 1.25 ± 0.50 2 | 0.26 ± 0.12 1 | 2.18 ± 1.45 | 0.68 ± 0.51 |
| Edible NTFPs collection (kg $ha^{-1}$) | 124 ± 24 | 207 ± 5.34 | 30.41 ± 6.91 | 50 ± 12 | 105 ± 20 | 2.76 ± 1.05 | Not produced |
| Fodder collection (t $ha^{-1}$) | 2.36 ± 0.89 | 5.73 ± 2.54 | 0.21 ± 0.09 | 2.81 ± 1.35 | 3.57 ± 2.18 | 1.65 ± 0.65 | Not produced |
| Stand litter production (t $ha^{-1}$ $year^{-1}$) | 9.35 ± 3.26 3 | 7.34 ± 2.17 | 10.25 ± 0.46 | 4.80 ± 1.81 | 6.93 ± 2.51 | 1.98 ± 0.35 | Not collected |
| Crop residue (t $ha^{-1}$ $year^{-1}$) | 8.42 ± 2.47 | 0.17 ± 0.02 | Not collected | 3.24 ± 1.32 | Not collected | 1.53 ± 1.05 | Not collected |
| Floor litter (t $ha^{-1}$) | 5.23 ± 25 | 8.23 ± 2.15 | 34.91 ± 1.24 | 4.76 ± 2.11 | 26.87 ± 3.86 | 3.78 ± 1.25 | Not collected |
| Litter extraction (t $ha^{-1}$) | 0.21 ± 0.04 | 2.83 ± 0.85 | 1.21 ± 1.23 | 0.05 ± 0.01 | 1.56 ± 1.65 | 1.24 ± 0.52 | Not collected |
| Firewood extraction (t $ha^{-1}$) | 0.37 ± 0.15 | 1.78 ± 0.96 | 1.95 ± 0.23 | 0.21 ± 0.05 | 1.47 ± .24 | 3.42 ± 1.35 | Not collected |

Note: Agronomic yield includes cardamom capsule (fruit), crops yield, mandarin fruit, tea leaves and crop residue.
Values are pooled from three site replicates. Source: updated from Sharma et al. (2016)

## Costs and economic benefits

Traditional agroforestry systems have significant economic and social benefits for local communities. High-value cash crops provide farmers with income to support health care, education and social activities. Farm-based agroforestry systems also supply essential products for subsistence needs, such as food and nutrition. In addition to aesthetic and recreational benefits, agroforestry mountain ecosystems serve as important reserves of potable water and water for agriculture. Agroforestry practices provide a continuous supply of non-timber forest products, underutilized crops, and clean air, all of which improve the quality of life for mountain communities (Sharma et al. 2016). Table 2 shows that the costs associated with managing and maintaining traditional agroforestry systems differ, based on the system used.

**Table 2. Monetary input and output (USD ha-1), and cost-benefit analysis of seven agroforestry systems**

| **Input costs (USD)** | **1. Farm-based** | **2. Forest-based** | **3. Large cardamom based** | **4. Mandarin based** | **5. Crop, mix-tree-cardamom based** | **6. Slash-and-burn-based** | **7. Tea-based** |
|---|---|---|---|---|---|---|---|
| Labour employed for land preparation | 201 | 18 | — | 82 | — | 87 | — |
| Weeding | 28 | — | 20 | 40 | 27 | 46 | 10 |
| Labour employed for harvesting | 45 | 11 | 24 | 30 | 31 | 26 | 50 |
| Post-harvest management | 8 | — | 48 | 11 | 51 | 11 | — |
| Gap filling and replantation | 17 | 11 | 23 | 9 | 13 | 7 | — |
| Firewood for curing | — | — | 43 | — | 28 | — | — |
| **Total output benefits (USD)** | **299** | **40** | **158** | **172** | **150** | **177** | **60** |
| Agronomic yield | 545 | — | 1,761 | 1,136 | 1,140 | 561 | 37,500 |
| Firewood extraction | 25 | 121 | 123 | 14 | 74 | 10 | — |
| Fodder (tree/ground) extraction | 15 | 15 | — | 8 | 9 | 6 | — |
| NTFP/wild edibles extraction | 9 | 35 | 11 | 6 | 12 | 8 | — |
| **Total** | **594** | **171** | **1,895** | **1,164** | **1,235** | **585** | **37,500** |
| Output: Input ratio | 1.99 | 4.17 | 11.99 | 6.77 | 8.23 | 3.31 | 625.00 |

Note: Values are pooled from three site replicates. Source: updated from Sharma et al. (2016)

The output-to-input ratio was highest for tea-based agroforestry and lowest for farm-based agroforestry. These results indicate that the choice of agroforestry system can significantly affect both the costs and benefits of production. Therefore, careful consideration should be given when selecting the most suitable agroforestry system. These findings could be used to inform decision-making by stakeholders involved in agroforestry systems, including policymakers, farmers and researchers.

## Functions and services of traditional agroforestry in Sikkim

The cultivated systems located adjacent to the protected area network in the eastern Himalayan region provide a vital biological corridor for the movement of wild animals designated as flagship species, along the Himalayas within India, and across the border towards Bhutan in the east, the Tibetan Autonomous Region of China in the north and Nepal in the west. Agricultural landscapes are crucial in supporting globally threatened and biologically restricted species, thus maintaining biological connectivity. In the region, wild biodiversity and traditional agroforestry are continuous landscape elements characterized by a close interaction between people and natural systems.

In the Himalayan watershed, conventional agriculture is associated with high overland flow and soil and nutrient losses. In contrast, traditional agroforestry practices conserve soil and nutrients, which helps to maintain ecosystem services and biodiversity (Pandey et al. 2013). These agroforestry systems provide diverse functions that support ecological sustainability: maintaining soil fertility, conserving resources, enhancing productivity, and reducing erosion. Operated by smallholders, they meet market demands through sustainable production. They suit marginal lands, and support impoverished and Indigenous people (Sharma et al. 2007). They also enhance resilience, providing forest cover and perennial cash crops.

Traditional agroforestry systems have a remarkable level of crop diversity (Table 3), including a significant number of varieties for rice (88), maize (31) (Sharma and Pradhan 2023) and pulses and legumes (34), among others. Furthermore, these systems support a diverse range of plant species, including more than 483 medicinal and aromatic plants, 216 weeds, more than 250 fodder crops, 150 timber species, and more than 290 multipurpose tree species, as well as 20 bamboo species. These agroforestry landscapes are agricultural heritage systems that play a vital role in preserving genetic resources and maintaining agrobiodiversity.

**Table 3. On-farm species richness of crop varieties commonly grown in agroforestry systems of the Eastern Himalayas**

| Crop | Local name | Number of varieties |
|---|---|---|
| Rice (*Oryza sativa*) | *Dhan* | 88 |
| Vegetables | *Sabjiharu* | 75 |
| Fruits | *Falharu* | 63 |
| Eskush (*Sechium edule*) | *Eskush* | 55 |
| Spices | *Masala* | 38 |
| Pulses and beans/legumes (*Phaseolus* spp., etc.) | *Simbi-bori* | 34 |
| Tubers | *Tarul* | 33 |
| Maize (*Zea mays*) | *Makai* | 26 |
| Pseudo-cereals (lesser known crops) | *Geda-gudi* | 21 |
| Mustard (*Brassica* spp.) and other oil seeds | *Tori/Rayo* | 18 |
| Citrus (*Citrus* spp.) | *Suntola* | 13 |
| Banana (*Musa* sp.) | *Kera* | 9 |
| Finger millet (*Eleucine coracana*) | *Kodo* | 8 |
| Pumpkin (*Cucurbita* sp.) | *Pharsi* | 8 |
| Chilli (*Capsicum* spp.) | *Khorsani* | 8 |
| Taro (*Colocasia* sp.) | *Pindalu* | 6 |
| Ginger (*Zingiber officinale*) | *Aaduwa* | 5 |
| Buckwheat (*Fagopyrum tataricum*) | *Phaper* | 4 |
| Soybean (*Glycine max*) | *Bhatmas* | 3 |
| Barley (*Hordeum* spp.) | *Jau* | 3 |
| Wheat (*Triticum aestivum*) | *Gehun* | 2 |
| **Total** | | **520** |

## Conclusion

Traditional agroforestry systems in the Eastern Himalayas offer a sustainable approach to balancing short-term food and livelihood needs with long-term environmental conservation. These systems exemplify how agroforestry can improve the economic status of rural populations and enhance mountain ecosystem services. Conventional agriculture's sustainability suffers due to production-focused interventions, which sideline agroecosystem maintenance and smallholder employment. In the northeast Himalayas, small-scale mixed-crop rainfed systems are rooted in traditional mountain wisdom. Indigenous agroforestry knowledge declines with socioeconomic shifts, mirroring other developing nations. Trends vary due to agroecology, demographics and market access. Research must assess gaps, especially related to multipurpose trees. This aligns with productive traditions, buffers climate change, and sequesters carbon for resilience.

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