3 From Shifting Cultivation to Integrating Farming: Experience of Agroforestry Development in the Northeastern Himalayan Region

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Abstract

Northeast India comprising of eight states is known for biodiversity richness, which is intricately linked to the socio-culture of the indigenous people. In this region, livelihood is mostly dependent on traditional farming practices such as shifting cultivation, homegarden, taungya systems, etc. The crop combinations are based on the household requirements and have the basis of subsistence. Nonetheless, the cultural practices differed between different tribes in the region. As such, tree farming has been a traditional practice and agroforestry is also being practiced in different forms and formats. With the interventions of ICAR, several models of agroforestry right from horticulture-to-fish-based tree farming have been in practice. In the region, a new model of Intensive Integrated Farming System is being tested for its benefit-cost. As the hilly region receives high rainfall, the role of trees on the terrains receives much importance and as so is the influence of agroforestry practices on soil and water resources. Much research needs to be done on crop combinations with good input management for better socio-economic returns to the tribal farmers.

Introduction

Seven hill states that include Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura are collectively referred to as North Eastern Hill (NEH) region, located between 21°58′ and 29°30′ N latitude and 88°58′ and 97°30′ E longitude spread over 1,83,746 km^2 area (Wasteland Atlas of India 2010), bestowed with several traditional agroforestry systems

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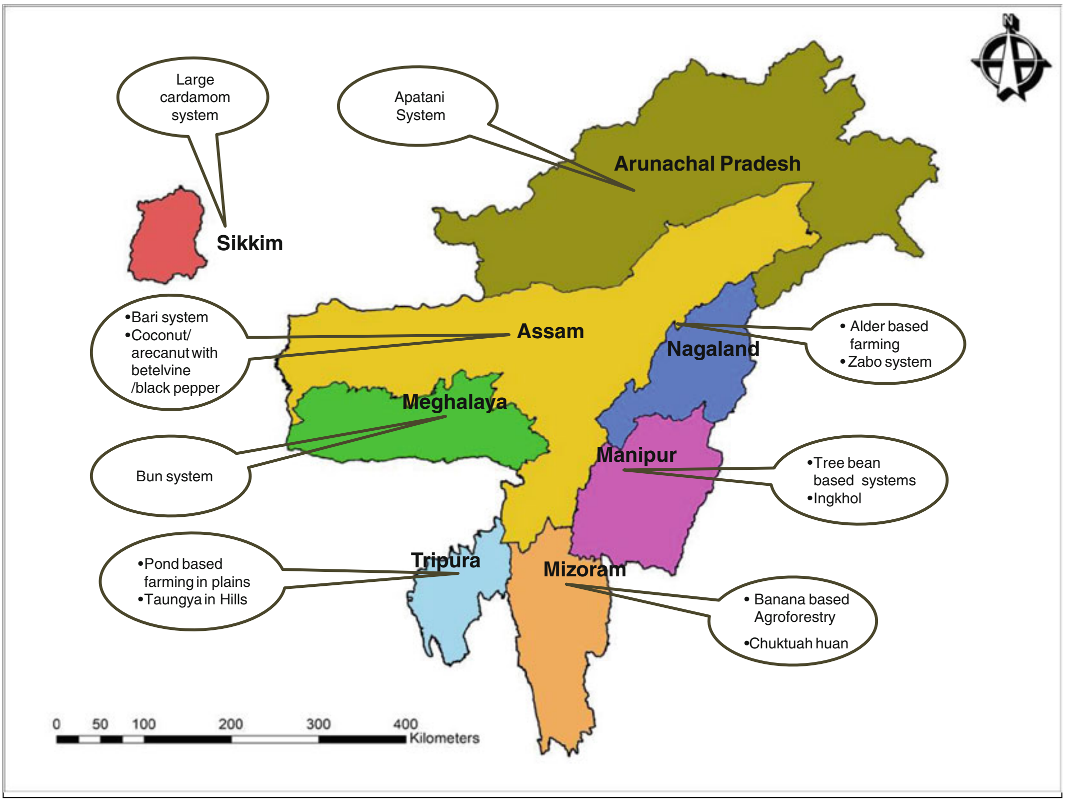

Fig. 3.1 Popular indigenous agroforestry systems in Northeast India

(Fig. 3.1). The region has unique weather and climatic conditions because of its typical geographical location, physiography, highlands in the northern part and their syntaxial bend, presence of alternating pressure cells of North West and Bay of Bengal and presence of tropical maritime air masses (Barthakur 2004).

Climate of the region varies from tropical to alpine type with very high range of variation in precipitation. The altitude ranges from 15 m to more than 5000 m above mean sea level. The temperature varies from as low as 0 °C in the Himalayan ranges (Arunachal Pradesh and Sikkim) to 35 °C in some parts of Tripura. The region receives highest average annual rainfall in the country, with Cherrapunji Plateau receiving over 11000 mm. This extreme variability in the precipitation, temperature, physiography, altitude, etc., has influenced the landuse, land cover, and species composition of the natural flora and fauna of the region. It is inhabited by more than 200 indigenous tribes having diverse lifestyle, cultural ethos, and multiple ethnicities resulting in multidimensional pressure on the natural resources. This unique and diverse climate has probably resulted in rich biological diversity and the region has the highest per capita availability of natural resources in the country. The region may be described as a cultural and genetic paradise and granary of mega biodiversity in terms of flora and fauna. It is one of the 12 mega centers of diversity and shares boundary with three out of the 34 internationally acknowledged hotspots of the world (www.biodiversityhotspots.org). Champion and Seth (1968) classified the forest types of the region as comprised of tropical moist evergreen forest to subalpine and alpine forests. About 80 % of the population lives in rural areas and majority of them depend on agriculture and allied sectors for their livelihood. Six distinct agro-climatic zones in different altitudinal range are there in the NEH (Table 3.1).

Table 3.1 Area under different agro-climatic zones of the NEH region

S. No.	Agro-climatic zone	Altitudinal range (m)	Approximate area (km^2) in the NEH region
1	Alpine zone	>3,500	47,068
2	Temperate subalpine zone	1,500–3,500	33,564
3	Subtropical hill zone	1,000–1,500	29,021
4	Subtropical plain zone	400–1,000	812
5	Mild tropical hill zone	200–800	26,349
6	Mild tropical plain zone	0–200	29,333

Despite having very high per capita availability of natural resources, diversified edapho-climatic conditions, and abundance of biological diversity, the region is still facing food grain deficit. The demand and supply gap in the poultry, meat, milk, etc., is also not positive and the region is importing these food items from other parts of the country. Because of undulating topography, the area under agriculture in the NEH region is very less which varies from 2.04 % of the total geographical area in Arunachal Pradesh to 22.90 % in Tripura. The productivity is low and soil degradation is high. Using Universal Soil Loss Equation (USLE), the annual average soil loss of 51 t ha^{-1} $year^{-1}$ was estimated for Dikrong river catchment in Arunachal Pradesh (Dabral 2002). Mandal and Sharda (2011a, b) reported that about 30 % of the total geographical area of the Northeastern Himalayas (including the NEH, Assam, and hills of West Bengal) are under the category of severe erosion having the potential erosion rate of 40–80 t ha^{-1}. For this region, estimation of acceptable rate of soil erosion (*T*-value) which is defined as the maximum permissible amount of soil erosion at which the quality of soil as a medium for plant growth can be maintained revealed that about 58.94 % of the total geographical area of this region requires various kinds of erosion management. Dhalai (North) of west Tripura hills is the major area of concern that can withstand maximum permissible soil loss of only 5.0 t ha^{-1} $year^{-1}$ (Mandal and Sharda 2011b). The changing climatic scenario is predicting further impact on the agricultural growth in the region. The Indian subcontinent is likely to experience a warming of over 3–5 °C leading to significant changes in precipitation pattern, flood, and drought situation (Ravindranath et al. 2011). The impact is supposed to be more pronounced in the northeastern Himalayan region. According to the recent report by the Ministry of Forest and Environment, Government of India, the yields of rice and maize in NER (including Assam) may decline up to 35 and 40 %, respectively, in the predicted climatic scenario of 2030 (Kumar 2011). Assessment of agriculture vulnerability in the projected future climate scenario (2021–2050) indicated that the districts of Tirap, West Siang, and Changlang will be the most vulnerable districts among all the NEH states. However, the vulnerability of West Sikkim, North Sikkim, East Sikkim, and Imphal will decrease from high to moderate levels (Ravindranath et al. 2011). Therefore, it is imperative to go for agricultural practices that are favorable to conservation of natural resources and resilient to the climatic aberrations. Agroforestry systems have the potential to address multifarious problems and deliver multiple benefits. It is effective in soil and water conservation through provision of permanent cover, improvement of soil health, enhancement of nutrient and moisture use efficiency, and moderation of microclimate. Agroforestry systems also have potential to limit carbon emissions and sequester carbon (Rao et al. 2007). The International Panel on Climate Change (IPCC) Third Assessment Report on Climate Change (IPCC 2001) states that "Agroforestry can both sequester carbon and produce a range of economic, environmental, and socioeconomic benefits. For example, trees in agroforestry farms improve soil fertility through control of erosion, maintenance of soil organic matter and physical properties, increased N, extraction of nutrients from deep soil horizons and promotion of more closed nutrient cycling."

The tribal communities of the northeast region practice varieties of agricultural practices ranging from different types of shifting cultivation systems, fallow system, home gardens, and sedentary agriculture such as wet rice cultivation. They have a natural inclination of keeping trees in their farming practices. The land use usually comprises a mixture of forest trees, animals, and field crops. These components are interdependent and strongly influence the livelihood of people of the region (Sundriyal et al. 1994; Mishra and Ramakrishnan 1982). The farming practices have evolved over centuries from the experiences of the people to meet the food, fuel, fodder, fiber, timber, and other such necessities.

Resource-Based Traditional Landuse Systems of the NEH Region

Shifting Cultivation

Shifting cultivation or *Jhum* is the most primitive and popular farming practiced across the entire NEH region which is essentially an agroforestry system organized both in space and time (Ramakrishnan 1992). The natural forests are removed for cultivation of crops (Fig. 3.2). Jhum is a way of life that is deeply entrenched in the artifacts, sociofacts, and mantifacts of the tribal way of life in the northeast (Murtem et al. 2008; Sailo 2011).

It locally known as *Rep Syrti* in Khasi and *Lo* in Mizo, has been practiced over 9000 years and said to have been originated in the Neolithic era dated by the archeologists to 7000 B. C. (Maithani 2005). At present, with increase in population pressure on land resources, the *Jhum* cycle is getting reduced very fast and reached at 2–4 years at present. This makes the system unstable and lead to severe land degradation as a result of soil erosion and associated factors such as reduction in soil organic matter, nutrients, etc. Total area under shifting cultivation is highest in Nagaland followed by Mizoram and Arunachal Pradesh. In terms of percentage of the total geographical area, Nagaland (17.06 %) and Mizoram (12.42 %) are the most severely affected by *jhum* cultivation. However, there is decline in area under shifting cultivation in most of the north eastern hill states except Nagaland (Table 3.2). It has declined from 1.35 million ha in 2003 to 0.85 million ha in 2005 (excluding the state of Assam).

The region is still rich in the forest resources in the era of rapid urbanization and economic development. The forest cover has not changed very significantly as compared to rest of the country (Table 3.3).

Important Attributes of Shifting Cultivation

One of the important common features of the shifting cultivation is growing of mixed crops after partial or complete removal of vegetation. In the northeastern India, many annual and perennial crops with diverse growth habits are being grown (Table 3.4) having sparsely distributed trees on hilly lands (Toky and Ramakrishnan 1981a). At times cash crops such as potato (*Solanum tuberosum*), rice (*Oryza sativa*),

Fig. 3.2 (*Left*) Forests have been cleared for shifting cultivation. (*Right*) Abandoned Jhum area in north-east India

Table 3.2 Area (ha) under shifting cultivation in different states of the NEH region

States	2005			2003				
	Current *Jhum*	Abandoned *Jhum*	Total	Current *Jhum*	Abandoned *Jhum*	Total	TGA (km^2)	Change (%)
Arunachal Pradesh	102,507	50,639	153,146	111,691	49,622	161,313	83,743	−5.06
Manipur	75,210	10,010	85,220	111,954	369,714	481,668	22,327	−82.31
Meghalaya	29,187	15,712	44,899	62,721	11,662	74,383	22,429	−39.64
Mizoram	102,853	158,903	261,756	114,695	287,046	401,741	21,081	−34.84
Nagaland	123,909	158,865	282,774	111,660	80,130	191,790	16,579	47.44
Tripura	8,928	16,483	25,411	28,489	11,037	39,526	10,486	−35.71
Sikkim	0	0	0	0	0	0	7,096	0
Total	442,594	410,612	853,206	54,121	809,211	1,350,421		−36.82

Source Wasteland Atlas of India 2010 (http://doir.nic.in/wasteland_atlas.htm) *TGA*, Total geographical area

Table 3.3 Change in forest cover in Northeast India

State	Total geographical area (km^2)	Forest cover in 2007, km^2 (%)	Forest cover in 2009, km^2 (%)	Change (km^2)
Assam	78,438	27,692 (35.30)	27,673 (35.28)	−19
Arunachal Pradesh	83,743	67,484[a] (80.58)	67,410 (80.50)	−74
Manipur	22,327	17,280 (77.40)	17,090 (76.54)	−190
Meghalaya	22,429	17,321 (77.23)	17,275 (77.02)	−46
Mizoram	2,1081	19,240 (91.27)	19,117 (90.68)	−123
Nagaland	16,579	13,464 (81.21)	13,318 (80.33)	−146
Sikkim	7,096	3,357 (47.31)	3,359 (47.34)	+2
Tripura	10,491	8,073 (76.95)	7,977 (76.04)	−96
Total North East	262,184	173,911 (66.28)	173,219 (66.07)	−692 (0.26 %)

Source Forest Survey of India (2009 , 2011)

[a] There was an interpretational change and upward revision of forest cover in 2009 in the state of Arunachal Pradesh by 131 km^2

Table 3.4 Mixed crops and their yield under different '*Jhum*' cycles of shifting cultivation in northeastern region of India

Types of crops/products	Total yield (t ha^{-1}) in 30 years	Yield (kg ha^{-1} $year^{-1}$) under 10 years "Jhum"	Yield (kg ha^{-1} $year^{-1}$) under 5 years "Jhum"
Grain/seed yield	2,585	1,339	130
Leafy and fruit vegetables	262	381	584
Tuber and vegetables	609	381	870
Cocoon (silk)	4	–	–
Pupae (without cocoon)	0.2	–	–

Source (Toky and Ramakrishnan 1981a)

Table 3.5 Changes in rates of accumulation of biomass, and primary productivity of successional communities during fallow periods of shifting cultivation in northeastern regions

Parameters	Successional age of fallow period (years)				
	1	5	10	15	20
Standing biomass (t ha^{-1})	5	23	57	10	150
Accumulation in boles and branches (t ha^{-1} $year^{-1}$)	4	4	7	9	8
Net primary production (t ha^{-1} $year^{-1}$)	5	8	14	17	18
Biomass accumulation quotient (standing biomass/net primary productivity)	0.9	2.5	4.3	5.9	8.3

Source (Toky and Ramakrishnan 1983)

Table 3.6 Nitrogen, phosphorus, and potassium losses (kg ha^{-1} $year^{-1}$) through runoff under *Jhum* cycles at lower elevation

Jhum cycle (years)	Runoff losses			Infiltration losses		
	NO_3–N	PO_4–P	K	NO_3–N	PO_4–P	K
5	5.3	0.9	51.0	9.2	0.1	13.7
10	4.2	1.3	91.2	10.7	0.1	21.2
30	3.7	1.1	64.7	9.8	0.1	15.1

Source Toky and Ramakrishnan (1981b)

maize (*Zea mays*), and ginger (*Zingiber officinale*) are grown in monoculture or mixed culture along with *Pinus kesiya*. Another important attribute of the system is secondary succession of vegetation during the fallow period. Toky and Ramakrishnan (1983) have identified various patterns in Northeastern India. They reported that standing biomass increased from 23 t ha^{-1} in one 5-year fallow to 150 t ha^{-1} in 20-year fallow. However, the rate of accumulation of biomass increased up to 15 years (when it was 9 t ha^{-1} $year^{-1}$) and it declined during succession up to 20 years (Table 3.5).

After the cropping phase of the system while burning the slash, the contents like carbon, nitrogen, and sulfur are lost due to volatilization. After the burn and before the onset of the first rains, sizeable quantities of nutrients are lost through blown-off ash due to strong winds during dry periods. The sediment loss during the cropping period was reported to be 30 t ha^{-1} $year^{-1}$ in a *jhum* cycle of 5 years (Table 3.6) and with the shortening of the cycle, the losses tend to be high (Toky and Ramakrishnan 1981b).

The soil loss from hill slopes (60–79 %) under first year, second year, and abandoned *jhum* was estimated to be 147, 170, and 30 t ha^{-1} $year^{-1}$, respectively (Singh and Singh 1981). During first few years of clearing, carbon and nitrogen levels decrease rapidly. According to one estimate annual loss of top soil was found to be 88.3 million tons and of N, P, and K 10669, 0.372, and 6051 thousand tones, respectively due to shifting cultivation in the region (Sharma 1998). Consequently, the total production from this cultivation is fruitfully low. The paddy yield in Khasi hills (Meghalaya), Garo hills (Meghalaya), Khonsa (Arunachal Pradesh), and Siang (Arunachal Pradesh) are reported to be 128, 504, 408, and 832 kg ha^{-1}, respectively.

Jhum in the region is a complex system with wide variation that depends upon the ecological variation in the area and cultural diversity among various tribal clans. However, there are some commonalities in the basic cropping practice. Usually all the essential crops such as paddy (*Oryza sativa*), maize (*Zea mays*), tapioca (*Manihot esculenta*), colocasia (*Colocassia esculenta*), millets (Species of *Panicum, Eleusine, Pennisetum*), sweet potato (*Ipomoea batatas*), etc., are grown on the same piece of land as mixed crop. *Jhum* in its most traditional form is

Table 3.7 Litter yield and N added through Alder

Alder population (trees ha^{-1})	Litter dry matter (kg per tree)	Litter yield (t ha^{-1})	N added (kg ha^{-1})
60	56.3	3.37	48.3
101	45.3	5.48	74.5
142	58.1	8.25	110.5
166	52.2	8.66	113.5
280	37.5	10.50	142.8
625	21.7	13.56	184.8

Source Sharma and Singh (1994)

not a very unsustainable landuse practice particularly when the *Jhum* cycle is more than 20 years. The soils get enough time to rejuvenate and restore their health and productive capacity. The Angamis tribe from Nagaland used to practice Alder (*Alnus nepalensis*) -based sustainable *Jhum* system that was developed in Khonoma village in Nagaland. It provides about 57 food crops to supplement the staple crop rice. The root nodules of the Alder plants improve soil fertility by fixing atmospheric nitrogen into the soil through *Frankia*. The fallen leaves act as mulches and add humus to the topsoil. The wood is used as fuel wood, for charcoal burning and in construction works. Alder saplings collected from nursery or wild forest are planted in a *Jhum* field located in hills above 1000 m. In the first year in *Jhum* plots, alder trees are pollarded at a height of 2 m from the ground before or after the slash and burn operation (Rathore et al. 2010).

Mixed cropping is repeated in the second year. The field is then left fallow for 2–4 years to allow the Alder trees to grow for pollarding and cropping in the subsequent cycle. Young trees with bole circumference of about 50–80 cm are pollarded for the first time, usually at the age of 7–10 years. Cyclical/subsequent pollarding is performed after 4–6 years. During this operation, the pollarded stumps that coppice profusely are allowed to grow till the harvest of the first year's crop. On the second year, 4–5 selected shoots are retained and the rest is removed. These shoots are allowed to grow till the next *jhum* cycle and the same process is repeated (Mishra and Sharma 2001; Pulamte 2008). Thus with the incorporation of Alder trees in their *jhum* lands, the fertility of the field is increased. It was estimated that the N_2 fixed from Alder plantation (Table 3.7) varied between 48.3 (60 trees ha^{-1}) to 184.8 kg ha^{-1} (625 plants ha^{-1}). Besides fixing atmospheric N_2, the litter added to the soil provided P, K, Ca, and other nutrient through the addition of biomass (Sharma and Singh 1994).

The Konyak tribes in Nagaland also have sound ecosystem knowledge which they use in their shifting cultivation practices. In a study in the Nganchin village of Mon district of Nagaland (Bhan 2009), it was observed that the tree-stand-density nowhere in the Naga system matches the Konyak system where at times about 3,000 small saplings could be observed in 1 ha of land. They gradually reduce the density during the fallow period. They manage the seedlings and saplings of *Macaranga denticulata* on the *Jhum* field and do not uproot them unless the density is too high for cropping. The species grows in poor site conditions and has prolific regenerative activity. Konyaks and the other tribes of Nagaland also keep the trees such as *Trema orientalis*, *Sapium bacatum*, *Grewia spp, Quercus spp, Schima wallichii*, and *Alnus nepalensis* in the Jhum fields. In the Konyak Jhum field about 42 species could be seen; rice and colocasia being the dominant ones. They have a sound knowledge of mixing rice and colocasia by which the sloping land is covered under vegetation for a greater part of the year, i.e., from April to December. Mixed cropping of rice and colocasia is also practiced by Garo and Khasi tribes of Meghalaya and they cultivate colocasia as a supplementary crop. But, Konyaks grow both the crops as their main crop to meet their food requirements. The common rice varieties cultivated by the Naga tribes are Tangyu, Yamsam, Phuha (Brown rice), Yam, Wungshu, Seshu, Tangyu seshu, Tatak, and Tanyak (black rice). As much as thirteen types of colocasia are grown by the Konyaks. Some of the important ones are Isee, Maywu, Mukshung, Yangshing, Tungmi, Nyakha, Tung, Yakpe, Ngaktung, Tunglu, Tungyey, Tungshu, and Tungkhan. However, with grater urbanization and changing food habit, the area under certain crops such as Job's tears (Coix lacryma-jobi) and some varieties of rice like Yam and Phuwal. The Konyaks have a good sense of fallow management and aware that the leaves and twigs falling from the trees restores the fertility of the *Jhum* land. They count the number of leaf falls and believe that after seven times 'leaf fall' the land becomes mature enough to cultivate. That is why they keep the fallow period as 7 years and deliberately keep the seedlings of tree species for establishment during the resting phase. They religiously protect the Jhum lands from fire during the fallow period. If some accidental fire occurs, the fallow period is extended. This shows the great sense of ecosystem among the Konyak tribes (Bhan 2009).

In the Khasi hills of Meghalaya, shifting cultivation is known as "*Rep Syrti*". Shifting cultivation or *Rep Syrti* practices are of two types—*jhumming* and Bun cultivation. *Jhumming* involves cutting and burning of forest vegetation on sloping lands and using the site for 2–3 years for growing rice, maize, millets, beans, cassava, yam, sweet potato, ginger, chilies, sesamum, and vegetables in mixture thereafter moving to a forest site for repeating the same process (Singh and Prasad 1987; Singh and Dhyani 1996). At times, a single crop of rice is grown in the second year of *jhumming*.

In Bun cultivation (Fig. 3.3), twigs and branches of forest tree species such as *Pinus kesiya*, *Schima wallichii*, *Michelia* species at lower elevations, and *Schima khasiana* in higher elevation along with weed biomass (*Artimisia vulgaris*, *Crotolaria mysorensis, Eupatorium odoratum*, *E. adenophorum, Imperata cylindrica*, *Inula capa*, *Lantana camara*, *Micania macarantha*, *Panicum khasianum*, *Plectranthus*

Fig. 3.3 *Bun* method of cultivation along the hill slopes in Meghalaya

coetsa, *Rubus ellipticus*, *Saccharum spontaneum*, *Pteridium aquilinum)* from the surrounding areas are kept in heaps at regular interval in the entire area. The buns are usually 2–4 m long, 1–2 m wide, and 0.15–0.35 m in height. They are spaced at 1–2 m depending on the soil depth and are covered with a thin layer of soil in order to burn the whole biomass under anaerobic condition and finally the biomass is slowly converted into ash. The activity is usually done during Feb to March (Singh and Dhyani 1996).

Zabo System

Zabo is an indigenous system of farming practice (Fig. 3.4) in many places of Nagaland. *Zabo* means impounding of water. The system has its origin in the Kikruma village of Phek district of Nagaland (Dabral 2002; Pulamte 2008). The system, mostly practiced by the Chakhesang tribe of Nagaland, is a combination of forest, agriculture, animal husbandry, and pisciculture. It is followed up to 100 % slope. Hill top is kept for forestry or catchment area and mid-slope is used for construction of silting ponds and water harvesting tank, land down for animal-yard, and finally the terraced rice fields. These ponds are desilted every year and the material containing soil and forest litter is spread in the fields for manuring. The water harvesting tank is rammed and compacted thoroughly at the bottom and the

Fig. 3.4 *Zabo* system of land management practiced in Nagaland

side walls are plastered with mud and chopped rice straw to prevent seepage losses. The water from the main tank is used for irrigation and is passed through the animal yard to carry dung and urine of the animals to rice fields. This way, around 80–100 kg N, 15–25 kg P, and 50–75 kg K per ha, besides organic matter and micronutrients, are added to the soil annually. A trench is dug-out in the rice field to rear fish. The farmers get reasonably good crop of rice without adding any inorganic nutrient, as well as enough fish for the family. Loss of the soil due to erosion is also below the critical limit (Sharma et al. 1994).

Other Traditional Agroforestry Systems

In the NEH region, trees are deliberately integrated with the crop and livestock production system. A number of crops like maize (*Zea mays*), rice (*Oryza sativa*), oat (*Avena sativa*), ginger (*Zingiber officinale*), turmeric (*Curcuma domestica*), cardamom (*Elettaria cardamomum*), Large cardamom (*Amomum subulatum*), pineapple (*Ananas comosus*), coffee (*Coffea arabica*), and vegetables are grown with forest and fruit tree species such as *Pinus kesiya*, *Alnus nepalensis*, *Schima wallichii*, *Pyrus communis*, *Prunus domestica*, *Areca catechu*, etc. The vegetables include cabbage (*Brassica oleracea* var *capitata*), radish (*Raphanus sativus*), pea (*Pisum sativum*), chilies (*Capsicum frutescens, C. acuminatum, C. annuum*), cowpea (*Vigna unguiculata*), soybean (*Glycine max*), rice bean (*V. umbellata*), pumpkin (*Cucurbita maxima, C. pepo*), cucumber (*Cucumis sativus*), okra (*Abelmoschus esculentus*), brinjal (*Solanum melongena*), tomato (*Lycopersicon esculentum*), bottle gourd (*Lageneria siceraria*), bitter gourd (*Momordica charantia*), potato (*Solanum tuberosum*), *Dioscorea* spp, etc., and climbers like black pepper (*Piper nigrum*), betel vine (*P. betel*), etc., are commonly cultivated. The choice of a particular tree species and intercrop depends upon the climatic conditions of the area and economic importance of the species. Some of the traditional agroforestry systems adopted in the various agroclimatic zones are given below in Table 3.8.

Some of these traditional agroforestry systems found in the region have very high productive potential. The most productive and widely adopted practice in the mild-tropical hills and plain zone is cultivation of pineapple and black pepper with areca nut. This system could generate net return of INR 43,000 ha^{-1}. In the temperate and subalpine zone, plum with potato/cole crops generated a net income of INR 19,000 ha^{-1} (Singh and Dhyani 1996; Bhatt et al. 2001).

Large Cardamom Agroforestry System of Sikkim

Large cardamom (*Amomum subulatum*) is an important cash crop of Sikkim that grows under the forest canopy as well as cultivated with retained trees (Fig. 3.5). Its cultivation is ecologically and economically viable traditional agroforestry system in Sikkim. Earlier, the ancient inhabitants of Sikkim, the Lepchas, used to collect large cardamom from the natural forest. With the progress of civilization, the crop got domesticated; people started cultivating the species by deliberately keeping some trees in the farm to provide the required niche to the cardamom crop. The choice of species was based on their needs experience and traditional knowledge. The crop is now cultivated up to 2,000 m above mean sea level, the lower limit being 600–800 m above msl. Many varieties of cardamom such as Ramsay, Sawney, Golsey, Bharlang, Madhysey, Ramla, etc., are cultivated to get desired quality

Table 3.8 Common agroforestry practices of the NEH region

Agroclimatic zone	Agroforestry system/ practice	Tree components	Inter crops
Mild tropical hills to mid hill subtropical and plains (200–900 m)	Agri-horticultural	*Citrus grandis*	Maize
		Orange (*C. sinensis*)	Beans/chilies/ginger/turmeric
	Agri-silvicultural	*Lagerstroemia speciosa*	Paddy
		Bambusa pallida (boundary plantation)	Paddy
		Schima wallichii	Paddy
		Michelia oblonga	Paddy
		Michelia champaca	Paddy
		Pinus kesiya	Paddy
	Agri-silvicultural system	*Pinus kesiya*	Turmeric and maize
		Bambusa pallida + *Erythrina indica*	Maize, sweet potato
	Homesteads/ gardens	Guava, banana and *Moringa*	Vegetables
		Coconut, arecanut, jackfruit, and banana, etc., around fishponds near homesteads	Vegetables
	Horti-pastoral system	*Musa paradisiaca*	Broom grasses
		Musa paradisiaca, Citrus reticulata	Setaria, broom grass
	Agri-silvicultural systems	*Schima wallichii*	Ginger, colocasia, chili, dioscorea, pumpkin, and Sweet potato
		Michilia oblonga	Ginger
		Erythrina indica (boundary plantation)	Ginger, colocasia, Lady's finger, sweet potato, chili, perilla
		Bambusa pallida (boundary plantation)	Paddy, ginger, sweet potato, chili, tapioca, lady's finger's, colocasia, perilla
		Michelia oblonga, Pinus kesiya +	Ginger, chili, colocasia, perilla, maize, turmeric
		Erythrina indica with coffee	Vegetables and black pepper
		Terminalia myriocarpa with coffee	Black pepper
		Schima wallichii	Ginger, colocasia, chili, dioscorea, pumpkin, sweet potato
		Pinus kesiya	Ginger

(continued)

Table 3.8 (continued)

Agroclimatic zone	Agroforestry system/practice	Tree components	Inter crops
	Multi-tier horticultural	Arecanut	Betel vine, pineapple, black pepper
		Banana	Pineapple
		Artocarpus heterophyllus, Litchi chinensis	Ginger + colocasia + maize + bottle gourd
		Artocarpus heterophyllus, Litchi chinensis, Areca catechu	Betel vine
		Musa paradisica	Pineapple
		Acacia catechu	Pineapple
	Silvihorticultural	*Acacia auriculaeformis*	Pineapple
		Acacia auriculiformis. Schima wallichii, Musa paradisica	Pineapple
		Pinus kesiya	Ginger
	Silvo-pastoral system	*Schima wallichii*	Broom grass
		Michelia oblonga	Broom grass
		Michelia champaca, *Schima wallichi*, *Pinus kesiya*	Broom grass, *Setaria*
	Sericulture-based farming	*Morus laevigata, Terminalia sp*	Pulses, oilseeds, broom grass, millets, oats
	Bamboo-based farming	Species of *Chimonobambusa., Dendrocalamus, Bambusa, Drepanostachyum intermedium, Phyllostachys bambusoides*	Tender bamboo shoots collected, ginger, turmeric, large cardamom, rice bean (up to 11–15 m from bamboo rows)
	Agri-horticultural	Sikkim mandarin	Maize-wheat Maize + ginger/buck Wheat/millet/pulses/vegetable/beans/radish/hara simbi/ricebean Maize + soybean/millet Ginger/rice bean Maize/sweet potato/millet/buck wheat/vegetables beans/radish
		Pyrus communis	Maize + cabbage + cauliflower

(continued)

Table 3.8 (continued)

Agroclimatic zone	Agroforestry system/ practice	Tree components	Inter crops
		Citrus reticulata	Turmeric + ginger + mustard
		Citrus grandis	Maize + turmeric + cauliflower + mustard leaf + potato
	Agri-silvi-pastoral	*Alnus nepalensis, Schima wallichii, Prunus cerasoides, Terminalia myriocarpa, Castonopsis tribuloides, Litsea polyantha, Macaranga denticulata, Ficus sp.*,	Maize, wheat, pulses, buckwheat, oilseeds, beans, finger millet, broom grass
	Homestead	*Sikkim mandarin, citrus,* Ficus, *guava, pear, pomelo, papaya, pomegranate, avocado, banana*, Urtica sp., Artemisia	Vegetables, tomato, passion fruit, gladiolus, tuberose, marigold, orchids, sugarcane, pig, poultry, cattle, goats, ducks, wild edibles-ferns, nettles, fishery, mushroom, apiary
II. Subtropical Hills to subtemperate hills and Plains (900–1,500 m)	Horti-silvicultural	*Alnus nepalensis/Schima wallichii*	Large cardamom (*Amomum subulatum*)
		Schima wallichii	Pineapple
		Schima wallichii	Ginger/turmeric
		Alnus nepalensis, Schima wallichii, Macaranga pustulata, Albizia sp., Machilus edulis, Saussurea nepalensis, Terminalia myriocarpa, Juglans regia	Large cardamom
	Multi-tier horticultural	Khasi mandarin (Citrus reticulata)	Pineapple/beans/radish/ginger/turmeric/cole crops, etc
III. Subtem perate-Temperate (1,500–2,700 m)	Horti-pastoral system	Pears with vegetables/beans/broom grass	Pears with cabbage, cauliflower, beans, or broom grass
	Horti-silvi-pastoral	Apple, *Juglans regia, Alnus nepalensis, Prunus nepalensis, Quercus* sp., *Betula alnoides, Acer* sp., *Hippophae salicifolia*	Maize, millets large cardamom, potato (table and seed), peas, cabbage, cauliflower, beans, radish
	Horti-silvicultural	Pine with field/vegetable crops	Pine trees with pea, radish, potato, sweet potato, cabbage, turnip, cauliflower, mustard, or maize

(continued)

Table 3.8 (continued)

Agroclimatic zone	Agroforestry system/practice	Tree components	Inter crops
		Plums	Plums, vegetables, pea, radish, cabbage, or cauliflower
	Livestock-based mixed farming	*Betula utilis*, *Acer* sp., *Rubus* sp., *Viburnum erubescens*, *Berberis* sp., *Urtica* sp., *Artemisia* sp.	Goats, pig, sheep, poultry, nomadic herds of yak (dzo's). Grasses like *Imperata cylindrica*, *Arundinella* sp., *Avena* sp., *Eleusine* sp., *Setaria* sp.
	Multi-tier horticultural	Apple with field/vegetable crops	Apple (*Malus pumila*) + potato
Subalpine to Alpine (2,700–4,000 m)	Horti-pastoral-transhumance	*Quercus* sp., *Acer* sp., *Betula utilis*, *Sorbus* sp., *Carex* sp., *Trisetum* sp.	Radish, peas, potato, beans, maize, cabbage, cauliflower, *Brassica juncea* var. *ragosa*, yaks (dzo's) sheep, goats, mules. Grasses *Eragrotis* sp., *Aralia* sp., *Allium* sp., *Iris* sp.
	Livestock-based mixed farming (beyond timberline)-transhumance	*Poa* sp., *Agrostis* sp., *Carex* sp., *Gentiana* sp., *Rumex* sp., *Phlomis rotata*, *Urtica dioca*	Potato, cabbage, peas, *Brassica juncea* var. *ragosa*, yaks (dzos), sheep, and mules

For scientific names of crops and vegetables see the text before the table
Source Chauhan and Dhyani (1990, 1991), Avasti (2006), Bhatt et al. (2006)

and yield. About 30 tree species are used to provide shade to the cardamom plantation and *Alnus nepalensis* is the most commonly used tree species (Singh et al. 1982). The other commonly used woody perennials are *Schima wallichii*, *Engelhardtia acerifolia*, *Eurya acuminata*, *Leucosceptrum canum*, *Maesa chisia*, *Symplocos theaefolia*, *Ficus nemoralis*, *Ficus hookeri*, *Nyssa javanica*, *Osbeckia paniculata*, *Viburnum corylifolium*, *Litsea polyantha*, etc. (Singh et al. 2005). This system supports highly diverse tree species and the diversity index of the cardamom agroforestry system is more than the other agroforestry systems practiced in the region (Sharma and Sharma 1997). The system produces 4.5–5.5 t ha^{-1} $year^{-1}$ woody biomass which is enough to meet the fuel wood requirement (800–1000 kg for curing cardamom produced from one ha of mixed forest) for cardamom processing and other domestic requirement (Sharma et al. 2000).

Majority of the cardamom plantations have Himalayan Alder (*Alnus nepalensis*) as shade tree as the combination of Alder and cardamom is sympatric and proved to be economically viable and ecologically sustainable. *Alnus nepalensis* is a *Frankia* mediated nitrogen fixing tree species and the net primary productivity is more than the other mixed forest species. The practice of using *Alnus nepalensis* as shade tree (Fig. 3.6) has been adopted by the indigenous communities to maintain soil fertility and to sustain productivity (Sharma et al. 1994). Sharma et al. (2000) reported that the yield of finished cardamom under Alder (454 kg ha^{-1} $year^{-1}$) is almost double than the cardamom produced under natural forest canopy (205 kg ha^{-1} $year^{-1}$). The Alder-based cardamom agroforestry system has the potential to generate net income of INR 80,000–90,000 ($2191.6 USD) per ha per annum (Sharma et al. 2009).

Banana-Based Agroforestry in Mizoram

Banana (*Musa* x *paradisiaca*) is a preferred crop in most parts of Mizoram. In the *Khumtung* and *Baktwang* village, people have a belief that

Fig. 3.5 Large cardamom-based agroforestry systems of Sikkim (Northeast India)

Fig. 3.6 Alder (*Alnus nepalensis*)-based agroforestry system in Nagaland (Northeast India

planting banana would protect them against all the natural calamities and misfortune besides giving them good economic prosperity. Along with banana other annual crops, leafy vegetables like Lai Pata (variety of *Brassica juncea*) are grown. Nowadays, people also grow the fruit crops like lemon (*Citrus limon*) and orange (*Citrus sinensis*).

Home Gardens/Homesteads

Home gardens also known as homestead, are usually small plots of land near the house/surrounding the house on which a mixture of annual and perennials are grown together with/without animals and are mostly managed by the family members primarily for their own use and occasionally for commercial purposes. Home gardens are the ancient agroforestry systems with a lot of complexities in structure and multiplicity in function. The composition of the home gardens are governed by the edapho-climatic conditions of the area, socio-economic conditions and cultural orientation, and personal and situation-specific needs of people. Therefore, home gardens usually have an inbuilt strength of meeting the basic needs of people such as spices, condiments, fruits, vegetables, timber, fuel, fiber, etc. Size of these gardens in the northeast India varies from 0.02 to 2.0 ha with a mean from 0.2 to 0.3 ha (Rastogi et al. 1998; Das and Das 2005; Sahoo et al. 2010).

Significance of Home Gardens

Conservation of Biodiversity

They are normally multilayer in structure having a close nutrient cycling system and often act as a repository and testing site for uncommon species, varieties, and land races of plants. Therefore, home gardens are important in situ conservation sites and in accordance with the convention of Biological Diversity Act, Article 7, 8, and 10 (c), inventorization of such areas can help in identification and conservation of biological diversity (Das and Das 2005). For examples, certain very hot chili varieties (varieties of *Capsicum frutescens*) with high capsicin content were selected and cultivated in Lotha and Konyak Naga home gardens. Many wild, rare tree species like *Aquilaria malaccensis* and *Vatika lanceaifolia* are conserved in home gardens because of their commercial value. Konyak Nagas successfully domesticated *Aquilaria agallocha*. Other rare species conserved in the home gardens are *Licuala peltata*, *Streblus asper*, *Meyna laxiflora*, etc. (Das and Das 2005). Multipurpose forest trees are cultivated in home garden of Kara (Rastogi et al. 1998).

Nutritional Security to the Family

Home gardens contain a number of species that fulfills the local dietary requirements, vitamins, and mineral supplements. Food crops dominate most of the home gardens. Sahoo et al. (2010) reported 107 species from different home gardens of Mamit district of Mizoram out of which 32 % were vegetables, 15 % fruits, 13 % medicinal plants, and 6 % spices. Nyishi tribal people in the foothills of Arunachal Pradesh grow on an average 15–20 species in their home gardens. A detail survey found that about 80 species are of ethno botanical importance and are grown by the Nyishi tribe in their home gardens and traditional agroforestry systems (Tangjang and Arunachalam 2009; Deb et al. 2009). In Konyak home gardens in Nagaland, about 157 plant products are used in local diets (Rastogi et al. 1998).

Strengthens Household Economy

Home gardens provide additional benefit and income for people. This is mostly achieved through saving money which otherwise would have been spent to buy the goods from the market. It is reported that in Indonesia and Nicaragua, home gardens contribute about 21.1 and 35 % of the total income, respectively. In southwest Bangladesh (Rahman et al. 2006) and Northeastern Bangladesh (Rahman et al. 2005), the income derived from home gardens is 15.9 and 11.8 % of the total household income, respectively. In Meghalaya, it was 7 % of the annual gross income per household (Tynsong and Tiwari 2010).

Angami Home Gardens

Angami Nagas are well acquainted with the environment around them and have learned to use and manage their limited land and water resources through experience and experimentations over the generations. They have developed excellent system of integrating Alder into their crop production system as they are aware about the beneficial affects of the species thorough their long experience. Angami territory is restricted to the southern Kohima district. In Angami territory, a large amount of land is available for wet or terraced rice cultivation. It is a permanent agricultural system. However, because of intensive cultivation practices and low quality soils, the Angamis sometimes prepare new terraced fields and abandon the old ones. If these abandoned fields are close to the village, they are often used as home gardens.

The tradition of home garden is well developed and many are so extensive that there are areas for cultivation of maize and millets. Also large portion of Angami home gardens are occupied by commercial crops such as oranges and potatoes.

Three different types of homegardens are maintained by the Angami Nagas. They are (a) a small kitchen garden around the house with small plots for chili and vegetables with one or two fruit trees; (b) *tejeye*—larger traditional home gardens away from the house situated on terraced fields on the upper level and cultivated like home gardens but with planned commercial objectives, and (c) *mejeye*—community home gardens on community owned terrace fields cultivated like home gardens. Management practices are different for these three types of home garden systems. In *tejeye,* the main emphasis is on commercially important species such as potato and fruit trees, and intensive water management is observed. *Tejeye* is in fact the extension of terrace fields but is different in terms of plant composition. These home gardens have more perennials than are found in kitchen gardens. Decision making and selection of species are driven by market forces. Greater biodiversity is maintained in the kitchen gardens.

Many indigenous practices have been observed in the *tejeye*, for example, the traditional practices of manuring with *pidi* (*Solanum* leaves) to get rid of pests and insects. Alder trees increase soil fertility and improve the growth of fruit trees. Therefore, a few alder trees are maintained in these gardens. Trees such as *Melia* and *Cedrella* are also planted to increase soil fertility and control insect pests, while *Prunus* spp. are used as a wind break on terrace bunds.

Home Gardens of the *Konyak* Nagas of Nagaland

Konyak Nagas, considered the oldest tribe of Nagaland, are in fact expert agriculturists who, even today live in harmony with nature. Konyak(s) have successfully maintained a sustainable supply of natural resources for many years through various land management systems. These traditional systems of land management have been developed through indigenous knowledge blended with innovative skills. One of these traditional systems of land management is the home gardens maintained around the houses. A study conducted in three villages Liangnyu, Mon, and Tanhai from Mon district of Nagaland highlight the following details of home gardens.

Thirty-two home gardens were surveyed from three villages, of which 10 home gardens were from Liangnyu, 11 home gardens from Mon, and 11 from Tanhai (covering around 10–20 % of the total households). Tanhai had the maximum number of species (122) and the largest average size of home gardens. 87 species have so far been recorded from Mon and 45 species from Liangnyu. Konyak home gardens exhibited a wide diversity in size, shape, location, and composition. The management, organization, and spatial patterns show the maximum use of available land using different combinations of trees, shrubs, and herbaceous plant species in a year. Generally, selection of plants depends on daily necessities. Many of these species have multiple uses. The owners show a tendency toward cultivating mainly edible fruits and vegetables. Other categories include plants yielding timber, fuelwood, fumigators, masticators, species, beverages, construction materials, basketry material, medicines, poisons, and ornaments.

Ingkhol Home Gardens: The Home Gardens of *Meteis* of Manipur

The home gardens in Manipur is a traditional conservation area. The gardens locally known as *Ingkhol* are variable in size and shape. The home gardens vary from hill to valley, reflecting the variations of soil topography, climatic conditions, and cultural practices of the people. It appears that the regimes of moisture and nutrients must be varying in different areas, the penetration of light into gaps creating a heterogeneous landscape and promoting patchiness. In the valley, home gardens are quite diverse and complex. In hilly areas in the village that are permanent, large home gardens contain species for food, fiber, fuel, timber, medicines, and species of sociocultural importance. The hill home gardens have the following features:

(a) Cultivation of wild species such as oaks, cedars, toonas, and red wood.
(b) Economically important plants like *Ericas* and bamboos.
(c) Varieties of chili, tomato, and cabbage along with other local vegetables.
(d) Varied floristic patterns, representing trees form valley and hills.

These home gardens are a mosaic and include the following components:

(a) Perennial, multipurpose trees of horticultural importance, timber or medicines.
(b) Various microhabitats such as water resources with aquaculture of fish, mat grass, *Euryale ferox*, a traditional delicacy, fishery, poultry, cowshed, rabbit house, etc.
(c) Cash crop section for annuals.
(d) Frontal hut, *Shangoy* for socioreligious functions.
(e) Secret basil plant in the center of the court yard (*Shumang*)
(f) Separate areas for raising ornamentals, bananas, spices, vegetables.
(g) Fencing with bamboo species.

Home gardens are fenced by different bamboo species usually in the front and back, whereas the perennial species may demarcate the sides of it. The space for the traditional hut where the socioreligious functions are held is the characteristic feature of the traditional system in which the walls are made from thickly set reeds plastered with mud and the roofs are covered with thatch grass. This is the place where cattle may often be put for want of space. Fragrant flowers like *Thevesia, Nyctanthus, Jasminum*, *Lilics,* etc., and multipurpose banana plantations surround the deity temple located in front of the house. The back side of the residential unit is grassland with many grasses used for thatching, binding, and other purposes. Perennial wild or cultivated multipurpose trees characteristic of the region demarcate the ultimate boundary. There are five different canopy layers viz., emergent layer (15 m or more tall), main canopy (10–15 m tall), under story (5–10 m tall), shrubs (1–5 m), and herbs (less than 1 m) layer in the traditional home gardens maintained by Meiteis in the plains of the lower altitudes. The emergent layer mainly composed of *Artocarpus heterophyllus*, *Bambusa balcoa,* and *Acacia catechu*. The main caopy layer was dominated by *Mangifera indica*, *Parkia timoriana*, *Tectona grandis*, and *Toona ciliata*. The under story consisted of *Citrus grandis*, *Musa balbisiana*, and *Toona ciliata* and the shrub layer was dominated by *Melastoma malabathricum*, and *Adhatoda vasica*. The herb layer composed of vegetables and tree saplings such as *Clerodendron indicum*, *Corchorus capsularis*, *Areca catechu*, and *Citrus grandis.* The pond dykes were used for planting of *Neptunia prostrata* and *Ipomoea aquatica*. Vegetables formed the predominant category of plants followed by fruits and medicinal plants. Most of the households usually have *Parkia timoriana* and other legumes which they exchange among themselves. Plants such as *Eupatorium birmanicum*, *Ocimum santum,* and *Toona ciliata* are planted by the Meiteis for religious purpose. The plants such as *Pogostemon purpurascens* and *Ageratum conyzoides* are used for haircare. Most of the home gardens have a separate zone for spices like *Allium odorum, Eryngium foetidum*, *Houttuynia cordata,* etc. This practice of growing traditional spice crops in the *Ingkhol* by the Meiteis is a '*living heirloom'* that needs more in depth analysis.

Home Gardens of War Khasi Tribe in Meghalaya

War Khasi people, tribal community in the south Meghala, have a long tradition of forest conservation. Tynsong and Tiwari (2010) in a study in five villages in the south Meghalaya observed that the size of the home gardens varied from 200 to 3,500 m^2. They use seeds, seedlings, and vegetative propagules to regenerate home garden plants. Soil fertility of the home gardens is maintained by the addition of leaf litter, feces of reared animals, and kitchen waste manure. The home gardens usually have four strata. About 197 plant species (70 trees, 41 shrubs, 50 herbs, 23 climbers, and 13 epiphytes) were reported to be used by the tribe. They place the plants in distinct groves such as arecanut grove, banana grove, fruit grove, vegetable garden, orchid grove, etc. Arecanut zones are the most important ones that are common to most of the home gardens. The average income from the home gardens is about 7 % of the total household income.

Chuktuah huan, the Home Gardens of Mizoram

Home gardens, locally known as *Chuktuah huan*, are the age old common practice in Mizoram. The home gardens normally have 3–4 strata/tiers having very high species diversity. The top layer or the dominant canopy consists of perennial tall trees like *Parkia roxburghii*, Jack fruit, Bamboo, etc. The second layer is mostly occupied by papaya, banana, tapioca, and yams. The first layer or the lowest strata consists of vegetables, tuber crop, pineapple, and grasses. The vegetables are also cultivated whereas the woody perennials and MPTs are planted near the periphery and boundary of the backyard. They also rear pigs, cows, chicken, and ducks for meat and egg purposes.

Research and Developments in the Field of Agroforestry in the NEH Region

Agroforestry is a complex landuse system which is practiced by people to derive multiple benefits from a piece of land. The Research and Development (R&D) aims to optimize these production systems with respect to economic viability and utilization of the natural resources like soil, water, and the biological diversity. It is a continuously evolving process and highly dynamic in nature that changes with time and space.

Multipurpose Tree Species for Agroforestry Systems in Northeast

Trees provide a range of significant products and services to rural and urban people. For any agroforestry programs, it is necessary to make an assessment of preferred and useful multipurpose tree species. The choice of species depends on the soil and climatic conditions of the locality and the nature of basic needs of people. Some of the MPTs suitable for agroforestry systems of the northeast region are listed in Table 3.9.

Fruit Trees Based Cropping Systems

NEH region has ample potential for fruit trees based agroforestry systems. For the development of suitable agorforestry system for the region, an experiment was conducted at ICAR Research Complex for NEH Regopn, Umiam where various fruit trees were grown with different combinations of agricultural crops. The results of different tree crop combinations have been summarized (Table 3.10). Khashi Mandarin (*Citrus reticulata*) was planted initially at a tree density of 800 trees ha^{-1}. However, it was observed that 400 trees ha^{-1} produced maximum yield. Average yield of Mandarin was 12.8 kg per tree after 7 years of plantation which increased up to 57.3 kg per tree after 12 years of plantation. In the inter row spaces of fruit trees, groundnut (*Arachis hypogaea*), soybean (*Glycine max*), turmeric (*Curcuma domestica*), ginger (*Zingiber officinale*), and local taro (*Colocacia esculenta*) were cultivated. The average productivity of these crops were 1.6, 1.5, 15.4, 10.0, and 17.0 t ha^{-1}, respectively.

With the increase in age of the tree crop and gradual closure of the over storey canopy, yield of groundnut and soybean started to decline. This opened scope to grow crops like ginger and turmeric and replace these oilseeds and pulse crops in the mandarin-based system. Among the field crops, ginger was the most remunerative. However, major share of income in these systems was generated by Khasi mandarin, which was about 80 % of the total income irrespective of the associated field crops.

In the guava (*Psidium guajava (*cv *Allahabad Safeda)*-based system was planted in association with five field crops namely groundnut, chili, soybean, turmeric, and ginger. Fruit yield of guava increased up to eighth year after which it started to decline because of fruit borer infestation. After 2 years of plantation, fruit yield was about 5.6 t ha^{-1} $year^{-1}$. Average yield of groundnut, chili, soybean, turmeric, and ginger were 1.8, 1.0, 0.7, 6.4, and 4.8 t ha^{-1}, respectively. Majority of the income was from ginger crop as the market price of guava was low as compared to mandarin.

In Assam, lemon (*Citrus limon*)-based cropping system was relatively more profitable than the guava-based system. Maximum fruit yield was attained after 7 years of plantation (34.8 kg per tree). Different intercrops such as ginger, turmeric, soybean, and radish were cultivated in the inter row spaces of these tree crops. The net return was maximum in Assam lemon + ginger (INR 35,000) followed by Assam lemon + radish crop (INR 14,120).

MPTs-Based Agroforestry Systems

NEH region is characterized by presence of vast tract of forest areas. Therefore, livelihood of the population is also strongly influenced by the forest wealth especially the tree resources. Farmers deliberately keep some of the multipurpose trees (MPTs) in their fields to meet their multifarious requirements. Therefore, some of the MPTs based agroforestry systems were also evaluated at the ICAR Research Complex at Umiam for their suitability for the region. Indigenous trees of the region like *Alnus nepalensis*, *Gmelina arborea*, *Michelia oblonga*, *Parkia roxburghii*, *Prunus cerasoides*, and *Symingtonia populnea* were planted at a density of 416 trees ha^{-1}.

Table 3.9 Important multipurpose tree species suitable for farming in different agroforestry systems

Plant species	Altitudinal distribution (m asl)	Important uses
MPTs		
Aesculus assamica	500–900	Fuel, small timber, fast growing
Albizia chinensis	700–1500	Fuel, fodder, timber, N_2 fixing species fast growing
A. lebbek	350–800	Fuel, fodder, timber, N_2 fixing species fast growing
A. procera	400–700	Fuel, fodder, timber, N_2 fixing species fast growing
Alnus nepalensis	700–2,500	Fuel, fodder, timber, N_2 fixing species fast growing
Altingia excelsa	750–2,100	Fuel, fodder, timber, fast growing
Anogeissus acuminata	800–1,300	Fuel, fodder, timber, slow growing
Anthocephalus chinensis	400–900	Fuel, fodder, timber, fast growing
Artocarpus chaplasha	500–1,500	Fuel, fodder, timber, fast growing
Bauhinia variegata	650–1,500	Fuel, fodder, ornamental, fast growing
Castanopsis indica	650–1,950	Fuel, timber, slow growing
Chukrasia velutina	200–1,400	Fuel, timber, fast growing
Cordia dichotoma	550–1,500	Fuel, fodder, fast growing
Debragesia salicifolia	700–1,800	Fodder
Duabanga grandiflora	150–800	Fuel, fodder, timber, fast growing
Exbucklandia populnea	900–2,400	Fuel, fodder, small timber
Ficus altissima	700–1,200	Fodder, fuel, fast growing
F. curtipes	600–1,000	Fodder, fuel
F. cyrtophylla	500–900	Fodder, fuel
F. elmeri	600–1,200	Fodder, fuel
F. gibbosa	1,000–1,800	Fuel and fodder
F. glomerata	700–1,800	Fuel, fodder, figs edible, fast growing
F. hirta	650–1,350	Fodder, fast growing
F. hispida	600–1,300	Fuel, fodder, figs edible, fast growing
F. hookeri	700–1,500	Fuel, fodder, fast growing
F. oligodon	600–1,400	Fodder, figs edible
Fraxinus floribunda	1,500–2,700	Light timber, ornamental, fast growing
Gmelina arborea	350–1,200	Fuel, fodder, timber, fast growing
Kydia calycina	500–1,200	Fuel, fodder, timber, slow growing
Largerstroemia speciosa	250–1,950	Fuel, fodder, timber
Litsea polyantha	400–900	Fuel, fodder, small timber, fast growing
Livistonia jenkinsiana	500–1,100	Leaves for roof making, new apicals as broom, fruit pulp edible
Macaranga denticulata	800–1,350	Fuel, fast growing
Mesua ferrea	350–1,700	Fuel, fodder, timber, avenue tree
Michelia champaca	200–900	Fuel, timber, avenue, fast growing

(continued)

Table 3.9 (continued)

Plant species	Altitudinal distribution (m asl)	Important uses
M. doltsopa	1,500–2,400	Fuel, timber
Moringa oleifera	100–800	Fodder, tender pods edible, fast growing
Morus alba	250–1,200	Fuel, fodder, sericulture, light timber, fast growing
Parkia roxburghii	500–1,500	Tender pods edible, light timber, fast growing
Pinus kesia	800–2,500	Fuel, timber, slow growing
Prunus cerasoides	800–1,500	Fuel fodder, fast growing
Prunus nepaulensis	1,800–3,000	Fuel, fodder
Quercus griffithii	1,500–2,650	Fodder, fuel, timber, slow growing
Q. serrata	800–2,500	Fodder, timber, slow growing
Q. semiserrata	600–1,500	Fodder, timber, slow growing
Salix tetrasperma	1,200–2,100	Fuel, fodder, small timber, fast growing
Sapindus mukorossi	150–1,500	Fuel, fodder, timber, ornamental, soap nuts as detergents, fast growing
Schima wallichii	350–1,700	Fuel, fodder, timber, fast growing
Shorea assamica	150–800	Fuel, timber
Sorbus cuspidata	120–450	Fuel, timber
Tectona grandis	100–650	Timber, slow growing
Terminalia bellirica	500–1,500	Fuel, timber, fruit medicinal, slow growing
T. chebula	450–1,500	Fuel, timber, fruit medicinal, slow growing
T. myriocarpa	300–1,100	Timber, slow growing
Toona ciliata	150–1,050	Timber, slow growing
Bamboos and canes		
Bambusa balcoa	10–1,200	Young shoot edible, fodder, culm used for various household activities, fast growing
B. bambos	150–350	Live fencing, pole, agricultural implements
B. polymorpha	15–110	Young shoot semi edible, house roofing, partition wall
B. jaintiana	1,100–1,900	Live fencing, fishing rod, winnowing tray, etc.
B. khasiana	1,100–1,900	Live fencing, fishing rod, winnowing tray, etc.
B. muliplex	800–2,100	Young shoot semi edible, live fencing, cane industry
B. nana	100–450	Construction purposes and cane industry
B. nutans	650–1,700	Young shoot edible, fodder, construction purposes
B. tulda	10–850	Young shot semi edible, fodder, construction purposes
B. vulgaris	700–1,700	Ornamental, construction purposes
B. wamin	550–1,000	Ornamental, construction purposes
Chimonobambusa callosa	800–1,300	Young shoot edible, construction purposes
C. hookeriana	500–2,100	Young shoot edible, construction purposes
Dendrocalamus giganteus	35–1,350	Young shoot edible, construction purposes
D. hookerii	1,100–1,900	Young shoot edible, fodder, construction purposes
D. longispathus	600–1,400	Young shoot edible, fodder, construction purposes
D. membranaceus	1,350–1,950	Young shoot edible, fodder, construction purposes
D. sikkimnensis	550–1,150	Young shoot edible, fodder, construction purposes

(continued)

Table 3.9 (continued)

Plant species	Altitudinal distribution (m asl)	Important uses
Gigantochloa rostrata	1,050–2,000	Young shoot edible, construction purposes
Melocanna baccifera	10–1,200	Young shoot edible, construction purposes
Phyllostachys bambusoides	850–1,850	Young shoot edible, cane industry
Schizostachyum dullooa	15–250	Young shoot edible, live fencing, cane industry
Teinostachyum wightii	550–1,100	Young shoot edible, live fencing, cane industry
Calamus spp	200–700	Furniture and various other household activities
Daemonorops spp	150–600	Furniture and various other household activities
Hedgerow species		
Cajanus cajan	150–950	Fuel, fodder, seeds edible, N_2 fixing, fast growing
Crotalaria pallida	150–960	Fuel, N_2 fixing, fast growing
Desmodium rensonii	400–1,000	Fuel, fodder, N_2 fixing, fast growing
Flemingia macrophylla	200-950	Fodder, N_2 fixing, fast growing
Indigofera tinctoria	250–1,200	Fuel, fodder, N_2 fixing, fast growing
Leucaena leucocephala	200–950	Fodder, fuel, N_2 fixing, fast growing
Mllettia ovalifolia	500–1,200	Fodder, N_2 fixing, fast growing
Tephrosia candida	300–1,000	Fuel, fodder, N_2 fixing, fast growing
Thysanolaena maxima	500–1,500	Fodder, Spikes as broom, fast growing

Compiled from various sources

After 12 years of growth, volume production was assessed for each species besides fuel and foliage yields. Volume production varied among different species and it was highest (2.07 m^3 per tree) for *Parkia roxburghii*, and lowest (0.43 m^3 per tree) for *Symingtonia populnea.* Though monetary input for each species was not considerably different, the output was highest (INR 1,854 per tree) for *Parkia roxburghii* followed by *Gmelina arborea* (INR 1,625 per tree) and *Michelia oblonga* (INR 1,157 per tree). After 12 years, on an average, farmers could get benefit of INR 361,000 from one hectare cultivation of these tree species only.

With these tree species, field crops soybean (*Glycine max* cv *Alankar*) and linseed (*Linum usitatissimum*) were intercropped up to fifth year. The net return was INR 1,625 ha^{-1} for soybean. Linseed was not economical as the net return was only INR 389 ha^{-1}. After that, pineapple (*Ananas comosus* cv *Kew*) was introduced with a density of 32,625 plants ha^{-1}. This is also most remunerative fruit crop of NEH region. The average net profit through intercropping of pineapple was INR 18,805 ha^{-1}, irrespective of tree species. After 5 years of plantation, crop composition was changed, and partial shade loving ginger (*Zingiber officinale* cv *Nadia*), turmeric (*Curcuma domestica* cv *RCT-1*), and local taro (*Colocasia esculenta*) were intercropped with MPTs. The net return was highest for ginger as compared to turmeric and taro, irrespective of tree species. Thus, based on 12 years research findings, ginger was found to be the most profitable intercrop, followed by pineapple.

Table 3.10 Performance of fruit tree-based cropping systems in the NEH region (No. of trees in each case was 400 ha^{-1})

Tree crop	Field crop	Variety of field crop	Net return (INR ha^{-1})
Khasi Mandarin	Groundnut	JL-24	4,541
	Soybean	Alankar	19,625
	Turmeric	RCT-1	30,375
	Ginger	Nadia	33,416
	Taro	Local	18,583
Guava	Groundnut	JL-24	3,000
	Soybean	Alankar	916
	Turmeric	RCT-1	2,750
	Ginger	Nadia	15,791
	Chilies	Local	1,125
Assam Lemon	Soybean	Alankar	2,583
	Turmeric	RCT-1	1,916
	Ginger	Nadia	36,625
	Radish	Japanese White	2,583

Prices are based on the market price of late 1990s
Source Annual Reports of ICAR Regional Research Complex of NEH

Three-Tier Agroforestry System in the NEH Region

In one experiment Alder (*Alnus nepalensis*-promising nitrogen fixing tree species) was planted as a tree crop during 1987 and tea (*Camellia sinensis*) was planted in 1993 as second storey crop at a density of 12,350 plants ha^{-1}. The investment for Alder and tea was INR 11,398 and 36,035 ha^{-1}, respectively. Besides tea, large cardamom (*Amomum subulatum*), turmeric, ginger, taro, and black pepper (*Piper nigrum*) were intercropped. Alder produced 850 kg ha^{-1} biomass of pruned material and 2.4 t ha^{-1} biomass of foliage. Green bud production of tea ranged from 4.4 to 6.4 t ha^{-1} for a period of 5 years with an average production of 5.9 t ha^{-1}. Productivity of large cardamom was 640 kg ha^{-1}. Ginger, turmeric, and taro produced 7.9, 16.5, and 17.2 t ha^{-1}, respectively. Black pepper was found to be sensitive to frost injury. Therefore, no significant yield could be obtained from this crop. Among various crops, net benefit was maximum (INR 33,111 ha^{-1}) through large cardamom, followed by tea and ginger. On an average, the multistoried agroforestry system could generate a net annual return of INR 12,884 ha^{-1}.

Silvopastoral Systems

Som (*Machilus bombycina*) tree is suitable for raring of *Munga* silkworm in Assam and its wood is used for tea-boxes. The tree attained average height of 6.75 m, 10.30 cm dbh and 0.046 m^3 volume in 5 years of plantation. Maize (*Zea mays*, cv. *Vijay* Composite) and broom grass (*Thysanolaena maxima*) were intercropped with it. Broom grass was cultivated on the terrace risers, covering total area of 480 m^2. Average grain production of maize was 1.2 t ha^{-1} in association with this tree crop as compared to 1.35 t ha^{-1} in control plots. Broom grass produced 6.3 t ha^{-1} of flower (most remunerative part of it), 8.6 t ha^{-1} of green fodder, and 3.6 t ha^{-1} of dry fuel wood. This system generated net return of INR 23,444 ha^{-1}.

Bhatt et al. (2010) evaluated seven MPTs such as *Acacia auriculaeformis*, *Alnus nepalensis*, *Bauhinia purpurea*, *Exbucklandia populnea*, *Ficus hookeri*, *Michelia champaca*, and *Michelia oblonga* with broom grass in the understorey in the mid hill conditions of Meghalaya. After 10 years, highest standing volume was recorded in *Acacia auriculaeformis* (220 m^3 ha^{-1}) followed by *Exbucklandia populnea* (120 m^3 ha^{-1}) and *Alnus nepalensis* (114 m^3 ha^{-1}). Yield of broom grass cultivated in the tree interspaces varied from 3.8 t ha^{-1} dry biomass (under *Bauhinia purpurea*) to 2.4 t ha^{-1} (under *Alnus nepalensis*).

Nonarable hilly areas with high slopes (>45 %) and low soil depth (<0.6 m) can be managed under suitable tree and grass combinations under livestock-based silvo-pastoral system. In an experiment at ICAR Research Complex for NEH Region, Meghalaya, 13.54 t ha^{-1} (dry matter) forage yield was obtained from combination of stylo (*Stylosanthes*) legume and *Setaria* grass with Alder. A combination of stylo and guinea grass (*Panicum maximum*) with Alder could produce 11.30 DM t ha^{-1}. In addition, Alder could provide 1.32 t ha^{-1} of fuel wood from the pruned branches.

Fish-Based Agroforestry System

The composite unit of aquaculture was consisted of paddy, vegetables, large cardamom, and fish culture besides bean cultivation on bund area of pond. It was revealed that among various components, fish culture generated maximum monetary returns (INR 36,000 ha^{-1}), followed by radish (INR 33,850 ha^{-1}), and cured large cardamom (INR 29,000 ha^{-1}) and brinjal (INR 25,500 ha^{-1}) cultivation, respectively. Average income from aquaculture-based system was INR 16,976 ha^{-1}.

Sericulture-Based Agroforestry System

Seven mulberry (*Morus alba, M. serrata, M. laevigata*) varieties, seven silkworm breeds including a bivoltine breed (NB-18) were studied for their yield and rearing performance. The results obtained are presented in the Table 3.11.

Intensive Integrated Farming System

Intensive integrated farming system (IIFS) is based on the concept that there is no waste in the system and the later is only a misplaced resource which can become a valuable material for another product (Edward et al. 1986). It is a more refined and holistic approach of land use system through practices in which a number of production components are integrated with the primary objective of developing a self-sustainable system. In IIFS all the components of agriculture like crop, fish, forestry, and horticulture are integrated in a complementary way (Bhatt and Bujarbaruah 2005). Fish fingerlings were introduced in each ponds @ 6000 fingerlings ha^{-1} with species composition of catla (*Catla catla*)—20 %, rohu (*Labeo rohita*)—10 %, mrigal (*Cirrhinus mrigala*)—20 %, silver carp (*Hypopthalmichthys molitrix*)—20 %, grass carp (*Ctenopharyungodon idella*)—20 %, and gonius (*Labeo gonius*)—20 %. Duck (Indian Runner and Khaki Campbell), pig (Large Black), layer birds (White Leghorn), goat (Black Bengal), and cow (*Holstein*) were reared and integrated with fishery. One pond was kept as control to compare the fish growth without integration of livestock/poultry/ducks. Vermicompost, liquid manure, and mushroom cultivation were started in IIFS. The five subsystems of IIFS were developed as detailed in Table 3.12.

The monetary input and output has also been calculated for each subsystem (Table 3.13). The total output/input ratio was highest (1.76) in crop–fish–dairy–MPTs–fruit trees–hedge rows–vermiculture–liquid manure–broom grass followed by Broiler chicken–crop–fish–duck–horticulture–nitrogen fixing hedge row (1.58). The monetary output/input could further increase if family labor is engaged for adopting IIFS (For detailed report, refer to Bhatt and Bujarbaruah 2005).

Water Conservation and Utilization

Out of 10 ha experimental site, 3.31 ha area was marshy where cultivation of crop was not possible. To rehabilitate such land, seven earthen water harvesting structures were created. Average cost involved for establishing these small water harvesting structures of 0.10–0.15 h, was INR 43,200 per pond. The average capacity of

Table 3.11 Yield of mulberry and silkworm cocoon in sericulture based agroforestry system

Mulberry variety	Plant height (m)	Yield (t ha^{-1} $year^{-1}$)			Net returns from cocoon (INR ha^{-1})
		Leaf	Cocoon	Fuelwood	
TR-4	1.70	19.1	0.81	6.4	33,449
TR-10	1.69	16.6	0.70	6.3	27,125
BC-259	1.44	15.2	0.65	5.7	23,627
S-1635	1.51	18.2	0.77	6.1	31,085
C-7635	1.52	16.5	0.70	5.6	26,865
Kanva-2	1.43	14.1	0.60	5.7	21,715
Local	1.28	9.1	0.39	4.1	8,215

Dhyani et al. (1996)

water retention ranged from 1000 to 1800 m^3 and average cost of one cubic meter water harvesting was estimated to be INR 32.36. It indicated that one liter of water could be harvested/conserved at price of INR 0.03 in first year itself which includes the cost of excavation, ramming, slope stabilization, plantation cost of planting Congo and guinea grass, spillway making, etc. Second year onward there was no cost involved except the maintenance cost whereas water could be harvested regularly. The details of water used for various purposes have been shown in Table 3.14.

Effect of Agroforestry on Soil and Water Resources

Effect on Soil Physico-Chemical Properties

Tree species ameliorate soil by adding both above and below ground biomass into the soil system. However, variations do exist in the inherent capacity of different tree species in rehabilitating degraded lands. Five different trees species suitable for agroforestry systems were studied at ICAR Research Complex for NEH Region at Umiam, Meghalaya by Saha et al. (2007). Soil samples were collected from 0–15 cm and 15–30 cm soil depth under five multipurpose tree species such as Khasi pine (*Pinus kesiya*), Alder (*Alnus nepalensis*), Tree bean (*Parkia roxburghii*), Champak (*Michelia oblonga*), and Gambhar (*Gmelina arborea*). A control plot in the form of natural fallow was also maintained near these tree-based land use systems for the purpose of comparison. Effect of tree species on bulk density (BD), organic carbon (OC), and porosity of the soil was significant. All the tree species lowered BD, and increased OC and porosity as compared to the natural fallow (Table 3.15).

The water stable aggregates (>0.25 mm) increased significantly under the different multipurpose tree species. Water stable aggregates were highest for the soils under *Pinus kesiya* (82.4 %) followed by *Michelia oblonga* (78.5 %) and *Alnus nepalensis* (77.6 %). Soil erodibility decreased with the tree species to the extent of 23.1–43.6 % as compared to control. Therefore, these species were instrumental in decreasing erodibility of soils of the NEH region. Protection of soils directly against erosive forces of raindrop and surface run off by improving physical and hydrological parameters of soil have been reported in many studies in India (Grewal and Abrol 1986; Deb et al. 2005; Jha and Mohapatra 2009).

Effect on Soil Hydrological Properties

Tree species improved moisture retention capacity of soil as compared to the control (Table 3.16). At -0.03 M Pa suction, soil moisture under different tree species was 21–36 % more than that of the control. Similar was also the trend in available water under the different tree-based systems.

Table 3.12 Description of IIFS models

Farming system	Land use component with area (ha)	Area (ha)	Description
Broiler chicken–crop–fish–duck–horticulture–nitrogen fixing hedge row	Pond—0.15 Pond dyke—0.03 Duck shed—0.016 Broiler shed—0.006 Field crop—0.75	1.06	In upland area, finger millet (0.18 ha), maize (0.30 ha), and rice bean (0.12 ha) followed by ginger and turmeric were cultivated during *kharif*. In lowland area, paddy (0.65 ha) and mustard 0.30 ha were cultivated. During *rabi* season potato, tomato, cabbage, knol khol, and radish were cultivated. Nitrogen fixing shrubs were planted on contour bunds, fodder grasses, and fruit trees were raised on pond dykes and farm boundaries. Ducks were reared (72 nos.) on pond dykes. Composite fish culture was practiced and 900 fingerlings were stocked
Crop-fish-poultry-multipurpose trees	Pond—0.12 Pond dyke—0.04 Poultry shed—0.01 Field crop—0.80	0.97	In upland area, paddy (0.45 ha) and rice bean (0.05 ha) during *kharif* and buckwheat (0.50 ha) in *rabi* season was cultivated. In lowland area paddy (0.30 ha) in *kharif* and potato (0.25 ha) and french bean (0.05 ha) were cultivated. Fodder grasses and fruit trees were raised on pond dyke and farm boundaries. Layer birds (52 nos) were raised on pond dykes. Composite fish culture was practiced and 720 fingerlings were stocked
Crop–fish–goat–MPTs–hedge rows	Pond—0.10 Pond dyke—0.035 Goat shed—0.008 Field crop—0.80 Hedge row—0.10	1.04	In upland area, paddy (0.30 ha), ginger (0.30 ha), turmeric (0.20 ha) during *kharif* and mustard (0.30), tomato (0.40 ha), and radish (0.10 ha) during *rabi* season were grown. Fodder grasses, MPTs and fruit trees were cultivated on pond dike and farm boundary. Goats (6 nos) were reared on pond dyke. Composite fish culture was practiced and 600 fingerlings were stocked
Crop–fish–pig–bamboo–MPTs–fruit trees–hedge rows	Pond—0.12 Pond dyke—0.035 Pig shed—0.001 Field crop—0.80 Hedge row—0.09 .	1.05	In upland area, paddy (0.30 ha), colocasia (0.10 ha) and maize (0.40 ha) during *kharif* and brinjal (0.10 ha), radish (0.05 ha), potato (0.30 ha), and buckwheat (0.15 ha) during *rabi* season were cultivated. MPTs and fruit trees were raised on pond dykes and farm boundaries. Edible bamboo species were also cultivated on farm boundary. Hedge rows of different species were planted on contour bunds. Vermicompost was prepared in two units each of $12' \times 6'$ x $2'$ size. Pigs (2 nos) on pond dykes. Composite fish culture was practiced and 720 fingerlings were stocked

(continued)

Table 3.12 (continued)

Farming system	Land use component with area (ha)	Area (ha)	Description
Crop–fish–dairy–MPTs–fruit trees–hedge rows–vermiculture–liquid manure–broom grass	Pond–0.12 Pond dyke—0.06 Dairy shed—0.016 Field crop—0.80 Hedge row—0.17	1.17	In upland area paddy (0.60 ha) was cultivated. Broom grass (0.10 ha) and job's tear (0.10 ha) were cultivated along the water channels. MPTs and fruit trees with fodder grasses were raised on pond dyke and farm boundary. Cattle (2 milch cows and 2 calves) was reared. Oyster mushroom was cultivated in 8 m × 3 m × 2.5 m size unit. Liquid manure was prepared in 3 units 3′ × 3′ × 2.5′ capacity. Vermicomposting was done in 6 units of 1 m × 1 m × 0.75 m. Composite fish culture was practiced in the six ponds. Composite fish culture was practiced and 720 fingerlings were stocked
Upland crops, and fish farming without integration (control)	Pond—0.10 Pond dyke—0.05 Crop area—0.80	0.95	In upland area, paddy (0.40 ha) and maize (0.40 ha) during *kharif* season and buck wheat (0.20 ha) and frenchbean (0.30 ha) were grown. Fruit trees were grown on pond dyke. Composite fish culture was practiced and 600 fingerlings were stocked

Table 3.13 Monetary output/input pattern (INR year^{-1}) of IIFS

Farming system	Total input	Total output	Output/input ratio (including labour component)	Output/input ratio (excluding labour component)
Broiler chicken–crop–fish–duck–horticulture–nitrogen fixing hedge row	1,05,722	1,67,331	1.58	2.24
Crop–fish–poultry–multipurpose trees	60,137	90,625	1.51	2.12
Crop–fish–goat–MPTs–hedge row	59,442	91,880	1.55	2.40
Crop–fish–pig–bamboo–MPTs–fruit trees–hedge rows	77,273	1,09,887	1.42	1.86
Crop–fish–dairy–MPTs–fruit trees–hedge rows–vermiculture–liquid manure–broom	1,70,120	2,98,735	1.76	2.48
Upland crops, and fish farming without integration (control)	31,773	34,894	1.09	1.50

Table 3.14 Water harvesting and utilization pattern in IIFS

IIFS	Water harvested in pond (m^3)	Water utilization (m^3)
Broiler chicken–crop–fish–duck–horticulture–nitrogen fixing hedge row	1,000	Fishery—924
		Vegetables—70
		Fruit trees—5.3
Crop–fish–poultry–multipurpose trees	1,800	Fishery—1675
		Vegetables—83
		Duckery—37
		MPTs—4.5
Crop–fish–goat–MPTs–hedge row	1,200	Fishery—1003
		Vegetables—67.5
		Poultry—126
		MPTs—3.2
Crop–fish–pig–bamboo–MPTs–fruit trees–hedge rows	1,300	Fishery—1170
		Vegetables—89.5
		Goat—36.0
		MPTs—4.5
Crop–fish–dairy–MPTs–fruit trees–hedge rows–vermiculture–liquid manure–broom	1,320	Fishery—1123
		Vegetables—76.5
		Pig—54.0
		Fruit trees—3.4
		Vermiculture—63.1

Table 3.15 Effect of various multipurpose trees on soil physical properties

Tree species	Organic C (g kg^{-1})	Bulk density (mg m^{-3})	Total porosity (%)	Micro aggregates (<0.25 mm)	Dispersion ratio	Erosion ratio	Erosion index
Pinus kesiya	3.54	1.04	54.3	17.6	0.21	0.20	0.11
	±0.33	±0.12	±6.22	±5.68	±0.09	±0.03	±0.01
Alnus nepalensis	3.22	1.09	55.6	22.4	0.23	0.23	0.12
	±0.47	±0.09	±5.87	±3.30	±0.05	±0.01	±0.02
Parkia roxburghii	2.31	1.23	52.2	28.8	0.26	0.30	0.14
	±0.61	±0.20	±3.20	±8.22	±0.11	±0.04	±0.01
Michelia oblonga	3.36	1.05	55.5	21.5	0.23	0.22	0.11
	±0.96	±0.32	±4.58	±7.45	±0.03	±0.03	±0.03
Gmelina arborea	2.86	1.14	52.4	38.0	0.25	0.24	0.12
	±1.24	±0.09	±6.04	±8.69	±0.04	±0.02	±0.02
Control (no tree)	1.56	1.32	48.7	44.2	0.35	0.39	0.15
	±0.92	±0.11	±8.09	±6.02	±0.06	±0.03	±0.03
LSD ($P < 0.05$)	0.39	0.15	5.06	3.05	0.06	0.05	0.03

Source Saha et al. (2007)

Table 3.16 Effect of various multipurpose trees on soil water retention characteristics

Tree species	Available water (m^3 m^{-3})	Infiltration rate (mm h^{-1})	Hydraulic conductivity (mm h^{-1})	Profile moisture storage (cm/ 60 cm)	
				In dry season	In rainy season
Pinus kesiya	0.220 ± 0.03	8.04 ± 1.28	5.44 ± 2.02	20.45 ± 3.22	24.60 ± 1.04
Alnus nepalensis	0.201 ± 0.02	7.28 ± 0.95	4.82 ± 1.46	19.44 ± 2.50	22.68 ± 0.98
Parkia roxburghii	0.192 ± 0.01	4.85 ± 0.56	3.23 ± 2.11	13.85 ± 3.61	18.52 ± 0.62
Michelia oblonga	0.210 ± 0.02	6.10 ± 1.23	4.84 ± 1.54	18.54 ± 2.37	21.66 ± 1.10
Gmelina arboria	0.183 ± 0.01	5.36 ± 0.82	3.50 ± 1.65	14.60 ± 2.11	19.41 ± 0.24
Control (No tree)	0.151 ± 0.02	3.84 ± 1.46	2.12 ± 2.35	11.45 ± 2.05	15.34 ± 0.72
LSD ($P < 0.05$)	0.11	1.06	0.18	2.17	2.30

Values for soil parameters are the means of three replications under two soil depths (0–15 and 15–30 cm) and two seasons across the year. Infiltration of water in the soil was also influenced by the tree vegetation. Infiltration rate under *Pinus kesiya* was almost twice that of the control (3.84 mm hr^{-1}).

Conclusions

In NEH Region agroforestry is a composite, diversified, and sustainable production system. It provides unique opportunity for integration of different components of the farming systems. This helps to optimize the ecosystem functioning and better management of land, water, and biological resources. In northeast hill region trees are deliberately grown with various crops and livestock under traditional production systems. Some of the systems developed for the NEH region have positive impact on the soil and water resources. These systems need to be further improved with suitable technological interventions to carter the needs of the local populace and help in improving the socioeconomic conditions of the farming communities. In NEH Region, agroforestry has gone a long way from traditional shifting cultivation to multienterprise farming systems where many components (based on the needs of the farmers) are integrated for getting optimum income providing the livelihood security.

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