2 Soil Conservation and Ecosystem Stability: Natural Resource Management through Agroforestry in Northwestern Himalayan Region

S. D. Kashyap, J. C. Dagar, K. S. Pant, and A. G. Yewale

Abstract

Northwestern Himalayan region is spread between 28°43′-37°05′ N latitude and 72°40′-81°02′ E longitude covering an approximate area of 33 million ha. The major natural resources of Western Himalayas are water, forests, floral, and faunal biodiversity. Forests constitute the major share in the land use of the region covering more than 65 % of the total geographical area of the region. The estimated annual soil loss from northwest Himalayas is approximately 35 million tons, which is estimated to cost around US $32.20 million. The rural population in Himachal Pradesh, Jammu and Kashmir, and Uttarakhand constitutes 90.2, 75.2, and 74.3 %, respectively as compared to the national average of 72.2 %. The livestock population in the region has increased tremendously during last three decades and is 21.33 million against human population of 29.53 million (1:1.38). The agriculture including livestock continues to be the dominant sector despite the fact that the area is exposed to adverse and harsh geophysical and agri-silviculture conditions. Strategies by planting fodder trees or grasses in the waste/degraded lands (representing 7.9, 9.8 and 11.5 % of the geographical area in Himachal Pradesh, Jammu and Kashmir, and Uttrakhand, respectively), is needed for enhancing the fodder production. In addition, farm spaces on terrace risers and improved crop production technology coupled with integration of agroforestry will help in bridging the gap

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between demand and supply of the fodder. The indigenous agroforestry systems such as homestead (*kyaroo*), plantation crop combinations, scattered trees on farm lands/field bunds and bamboo grove, etc., are practiced by the farming community. The land management operations are predominated by different indigenous agroforestry practices which have proven potential and hold promise in alleviating the poverty among rural masses of this hilly region. The agroforestry systems provide unique opportunity for integration of different components in the farming systems, which help to optimize the ecosystem functioning and better management of land, water, and biological resources. These systems need to be further improved with suitable technological interventions considering the local population need, so that the socioeconomic status of the farming communities uplifted. Experiences gained in managing natural resources through well-tested agroforestry systems have been shared in this chapter.

Introduction

The Northwestern Himalayan Region (NWHR) comprises of three states of the Indian Republic viz, Jammu and Kashmir, Himachal Pradesh, and Uttrakhand. Geographically it spreads between 28°43′-37°05′ N latitude and 72°40′-81°02′ E longitude covering an approximate area of 33 million ha contributing about 10 % of total geographical area of the country. The region occupies the strategic position in the northern boundary of the nation and touches the international borders of Nepal, China, and Pakistan. Most of the area is covered by snow-clad peaks, glaciers of higher Himalaya and dense forest covers of mid-Himalaya. The region comparatively shows a thin and dispersed human population due to its physiographic conditions and poor infrastructure development. The Himalayas exhibit great diversity in climate, landforms, ethnicity, resource availability, and agricultural practices.

The rural population in Himachal Pradesh, Jammu and Kashmir, and Uttrakhand constitutes 90.2, 75.2, and 74.3 %, respectively, as compared to the national average of 72.2 % (Census of India 2006). Agriculture, including livestock continues to be the dominant sector despite the fact that the area is exposed to adverse and harsh geophysical and agro-climatic conditions. Climate of the region is conducive for growth of a large variety of plants ranging from tropical to temperate due to different altitudinal ranges varying from 100 m above mean sea level (amsl) to more than 4000 m amsl, i.e., subtropical to cold temperate alpine zone. The region is the natural abode of large number of medicinal and aromatic plants and the value of medicinal herbs from forests is enormous. These medicinal resources are harvested as raw material from wild sources and majority comes from Himalayan region, i.e., temperate, subalpine, and alpine zones.

The Himalayan region has unique advantage and competitive edge over the adjoining states in the plains, i.e., Punjab, Haryana, and Uttar Pradesh due to diverse agro-climatic conditions for cultivation of off-season vegetables, temperate fruits, aromatic rice, and medicinal and aromatic plants, besides the huge potential for organic farming. The Himalayas have also contributed toward the formation of fertile plains. The estimated annual soil loss from northwest Himalaya is approximately 35 million tons, which is estimated to cost around US $32.20 million (VPKAS 2011). The land management operations are predominated by different indigenous agroforestry practices which have proven potential and hold promise in alleviating the poverty of hill people. The region is bestowed with rich natural resources including biodiversity; therefore, an attempt has been made in this chapter to justify the management of these resources through agroforestry which is a viable and most sustainable option for the fragile ecology of the region.

Ecology and General Features

The Western Himalayan region is a part of Hindu Kush Himalayas and is characterized not only by ecological fragility but also by a deep and historical geopolitical sensitivity (Stone 1992). There is considerable variation in climate, physiography, soil, and vegetation between the outer and inner Himalayas. Vegetation largely is controlled by altitude. The Western Himalayas are classified into Lesser Himalayas and the Greater Himalayas. The Lesser Himalayas lie in the north of Shiwalik hills. The mountain ranges in this region are usually 50–100 km wide and 1,000–5,000 m high. Dhauladhar range in Himachal Pradesh, Pir Panjal in Jammu and Kashmir, and Mussoorie in Uttrakhand are some of the important hill ranges. The Western Himalayan region has been divided into four agro-ecological zones (Fig. 2.1) as described in Table 2.1.

Climate

The Western Himalayan Region mainly experiences two seasons namely winter and summer. The average summer temperature in the southern foothills is about 30 °C and the average winter temperature is around 18 °C. In the middle Himalayan valleys, the average summer temperature remains around 25 °C while the winters are really cold. On the higher regions of the middle Himalayas, the summer temperature is recorded at around 15–18 °C while the winters are below freezing point. The region above 4,880 m amsl is below freezing point and is permanently covered with snow. During winters, the snowfall is heavy while the summers are much more mild and soothing. The Himalayan alpine climate varies according to the altitude. The climatic conditions change very quickly in the Himalayan region due to change in the altitude. The climate here is very unpredictable and dangerous too. The people in regions of Ladakh and Zanskar situated in the north of main Himalayan range are unaware of the monsoon season as the average annual rainfall is only a few centimeters (in the form of snow precipitation) resulting in very low humidity

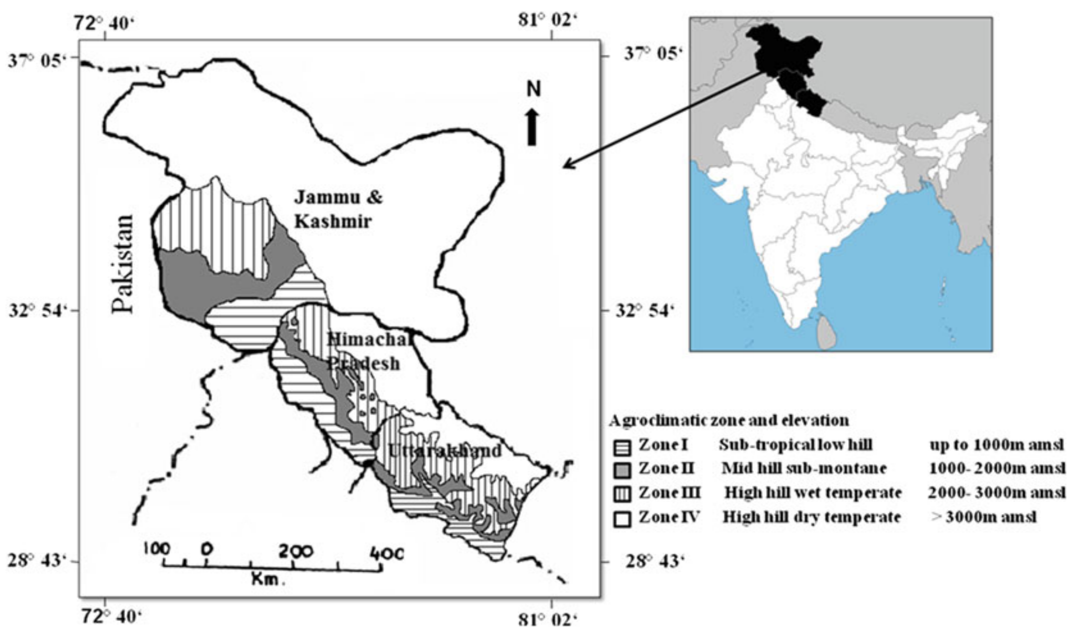

Fig. 2.1 Northwestern Himalayan region with agro-climatic zones

Table 2.1 Area under different agro-climatic zones of Northwestern Himalayan states

States	Agro-climatic zones	Tentative altitudinal ranges (m amsl)	Approximate area (000 ha)	Districts/parts of the state
Jammu and Kashmir	i. Low altitude subtropical zone	≤1000	1551	Jammu, Kathua, Udhampur, and parts of Doda and Rajouri districts
	ii. Mid to high altitude intermediate zone	1000–2000	1482	Poonch and major part of Rajouri, Anantnag, Pulwama, part of Doda district
	iii. Valley temperate zone and mid to high altitude zone	2000–3000 (<1200 Kashmir valleys)	1472	Srinagar, Baramulla, Kupwara and part of Anantnag, Pulwama, Budan, and Poonch
	iv. Cold arid zone (High hills dry temperate zone)	>3000	17719	Kargil, Leh, upper riches of Doda, Anantnag, Baramulla. Kupwara districts
Himachal Pradesh	i. Low hills subtropical zone	≤1000	924	Una, Hamirpur, Bilaspur and parts of Kangra, Chamba, Mandi, Sirmour, and Solan districts
	ii. Mid-hills subhumid zone	1000–2000	573	Part of Chamba, Solan, Shimla, Mandi, Sirmour districts
	iii. High hills temperate wet zone	2000–3000	1821	Parts of Chmaba, Kangra, Mandi, Sirmour, Shimla, and Kullu districts
	iv. High hills dry temperate zone	>3000	2249	Kinnaur, Lahaul Spiti, and parts of Kangra and Chamba districts
Uttrakhand	i. Babhar and tarai zone and subtropical low hills zone	<1000	1216	Haridwar, Udham Singh Nagar, and parts of Nanital, Dehradun, and Paurigarhwal districts
	ii. Hill zone[a] (a) Mid-hill subhumid zone	1000–2000	667	Parts of Garhwal, Nanital, Dehradun, and Champawat districts
	(b) High hills temperate zone	2000–3000	2935	Almora, Bageshwar, Tehri Garhwal, parts of Chamoli, Champawat, Rudraprayag, Nanital, and Uttarkashi districts
	(c) High hill dry temperate zone	>3000	1230	Parts of Chamoli, Rudraprayag, Pithoragarh, and Uttarkashi districts

Source Ghosh (1981)
[a] These zones are prepared on the basis of physiographic and altitudinal map of the states

levels. The region experiences coldest temperatures in the world during winter. Mostly the hill stations of the Western Himalayas like Srinagar, Pahalgam, Shimla, Manali (Kullu valley), Kangra, Dharamshala, Maclodganj, Chamba, and some regions in Uttrakhand like Kumaon and Garhwal experience the monsoon showers.

Natural Resources and Land Use Pattern

An ecosystem-based natural resource management approach is difficult to achieve as many countries in the north from west to east share the resources of this mountain system; whereas Indian Western Himalayan region resources are shared by many Indian states. The Himalayas are full of natural wealth, both renewable and nonrenewable resources. The major natural resources of Western Himalayas are water, forests, floral, and faunal biodiversity; and climate, soil, and ecology are the major determinants of the hill farming systems in different agro-climatic zones for livelihood subsistence.

The conservation of natural resources is not only essential for the food and livelihood security of the Himalayan states but also for the entire country. The hydrological potential of these states consists of vast and rich water resources as glaciers, rivers, and lakes. The high altitude areas of Lesser and Greater Himalayas are covered with glaciers and snow fields and are the origin of number of perennial rivers which heavily drain into Indus and Gangetic basin and form a most fertile Indo-Gangetic plain region of the country known as "food bowl of India." The hydropower and irrigation potential of these two important rivers is given in Table 2.2.

In Uttrakhand 31 natural lakes covering an area of about 300 ha and eight large-sized manmade reservoirs in Tehri and Udham Singh Nagar districts are covering an area of 20,075 ha. The Tehri dam is the largest dam in Uttrakhand followed by Sharda reservoir with 6,880 ha water area and Nanak Sagar reservoir with water area of 4,084 ha is the third largest in the state. These all reservoirs are owned by irrigation department and are used for irrigation purpose to enhance agricultural production. In Himachal Pradesh, the water from Beas and Sutlej rivers has been stored in Pong dam and Bhakra Govind Sagar reservoirs having capacity of 7,290 and 9,621 million cubic meters, respectively for irrigation and power generation. It is major source of irrigation to Punjab, Haryana, and Rajasthan. The catchment area of Ganga in India is approximately 863 thousand km^2 which covers about 26.2 % of the total geographical area of the country particularly of Northern States of Indian Territory and is considered as most fertile region of the world (State Profile Himachal Pradesh 2010).

Forests constitute the major share in the land use of Northwestern Himalayan region covering an area of about 1101, 2023, and 3486 thousand ha in Himachal Pradesh, Jammu and Kashmir, and Uttarakhand, respectively (Ministry of Agriculture 2009). Forests are the second largest natural renewable resources after water. The forest cover and canopy densities has a major role to maintain the hydrological regime in the region as well as to feed the adjoining plain areas for agricultural production. The very dense forests having canopy density more than 70 %

Table 2.2 Catchment area (km^2) and hydropower potential of different rivers in Himachal Pradesh[a]

Major basin	Tributary	Area (km^2)	Hydropower potential (MW)
A. Indus			
	Chenab	7,500	3,032
	Ravi	5,451	2,159
	Beas	20,402	4,604
	Sutlaj	20,000	10,355
	Total A	53,353	20,150
B. Ganga			
	Yamuna	2,320	592
	Total A + B	55,673	20,742
C. Mini-micro projects			
			750
Grand Total		55,673	21,492

Sources State Profile Himachal Pradesh (2010)

[a] Data for Jammu and Kashmir and Uttrakhand not available

and moderately dense forests having canopy density 40–70 % are generally found in high hill temperate wet and mid-hill subhumid zones of the region making it more humid with large number of natural springs due to deep soil percolation and interception of rain water into the soils of these forests. It also maintains optimum temperature for fruit and off-season vegetable production, conservation of biodiversity in the region and to maintain the hydrological potential of the perennial rivers round the year.

The growing stock of trees outside the forest land (ToF) under agroforestry or social forestry has played significant role to enhance the GDP of the country from 1 to 1.70 % (ICFRE 2010). The tree cover in the region increased significantly during last three decades when ICAR initiated All India Coordinated Research Project on Agroforestry (AICRP–AF) in collaboration with International Council for Research in Agroforestry (ICRAF), Nairobi, Kenya during 1982–1983 and farmers were encouraged to grow fodder trees on the bunds to meet the top-fodder demand during the lean period and timber trees to enhance their farm income and to meet their domestic demand. At present the total area under ToF in the region is 7,815 km^2 and total growing stock is 190 million cum (Table 2.3).

The research under AICRP-AF during the last three decades; number of indigenous agroforestry practices and multipurpose trees species (MPTs) are identified in different agro-climatic zones of the states and briefly discussed under various agroforestry systems, and research and development initiatives taken in agroforestry.

The livestock population in the region has increased tremendously during last three decades and is 21.33 million against human population of 29.53 million. In order to feed 21.33 million cattle in Northwestern Himalayan states, 1.35 million tons of fodder are required. The region does not produce adequate fodder and therefore, faces 54 % deficit in green fodder and 34 % deficit in dry fodder. Strategies by planting fodder trees or grasses in the waste/degraded lands which represent 7.9, 9.8, and 11.5 % of geographical area in Himachal Pradesh, Jammu and Kashmir, and Uttrakhand, respectively are needed for enhancing the fodder production. It is also needed to plant grasses, fodder bushes, and wild fruits on the forest floors to feed the wildlife and migratory shepherd (sheep and goats) during their journey from alpines to the lower hills (VPKAS, 2011). In addition, farm spaces on terrace risers and improved crop production technology coupled with integration of agroforestry, will help in

Table 2.3 Estimated production of forest resources in northwestern Himalayan region

Parameters	Jammu and Kashmir	Himachal Pradesh	Uttarakhand	Total
Annual estimated production of timber from forests (000 cum)	55	231	251	537
Annual production of fuel wood from forests (000 tons)	20	0.05	50	70.05
Growing stock TOF (million cum)	147.75 (6550)	21.15 (623)	20.92 (642)	189.82 (7815)
Annual production of timber from TOF (000 cum)	830	939	697	2466
Annual availability of fuelwood from TOF (000 tons)	365	290	297	952
Total live stock (million)	10.99	5.22	5.12	21.33
Livestock dependent on forests (million)	3.02	5.18	4.88	13.08

Source FSI (2011), Census of India (2011), HPFS (2011)
TOF Trees outside forest area in the form of social forestry, agroforestry, homestead, etc
Value in parenthesis represents the area under TOF in km^2

bridging the gap between demand and supply of the fodder.

Amongst other nonrenewable resources are deposits of boron, lead, lithium, coal, chromium, ores of iron, copper, tungsten, zinc, and deposits of building material like limestone, dolomite, and marble. These deposits occur across the length and breadth of the Himalayas cutting across international boundaries. The Himalayas have substantial mineral wealth due to which numbers of cement industries are coming up during last three decades in the region. The Himalayas present a storehouse of biodiversity, where flora and fauna vary extensively with climate diversity from one region to the other and this biodiversity is used for developing new varieties/hybrids in agriculture and horticultural crops to enhance the productivity.

Agriculture

There are several important valleys where intensive agriculture is practiced. These include Kangra and Kullu in Himachal Pradesh and Kashmir valley in Jammu and Kashmir and Doon valley and Babhar and Tarai region in Uttrakhand. In these low hills, agricultural fields are terraced in some parts except plain areas and fruit plantations are raised along with several arable crops, such as paddy, maize, pulses, wheat, oilseeds, potatoes, vegetables, etc. Cultivation is practiced up to 2500 m elevation. The contribution of agriculture and allied sectors to net state domestic product at factor cost (at current prices) in the region ranged between 16.8 and 28.9 % in the region (RBI 2010). The average operational holding in Jammu and Kashmir, Himachal Pradesh and Uttrakhand are 0.67, 1.07, and 0.95 ha, respectively, against the national average of 1.33 ha. The irrigated area in respective states is 42, 19, and 45 %, respectively of the net area sown (FAI 2010). If we consider only hilly region, these figures are much lower than the plains (Ramakrishna et al. 2000).

The crop production systems prevailing in Northwestern Himalayas are based on cereal crops, vegetables, horticulture under different agroforestry practices. Livestock is the integral part of farming in almost all three western Himalayan states. Wheat (*Triticum aestivum/durum*), paddy (*Oryza sativa*), maize (*Zea mays*), *Hordeum vulgare* (barley), *Elusine coracana* (mandua/ragi), *Pennisetum typhoides* (pearl millet), barnyard millet (*Echinochloa crus-galli*), oats (*Avena sativa*), *Amaranthus caudatus* (ramdana), rice-bean (*Vigna umbellata*), *Fagopyrum esculentum* (buckwheat), lentil (*Lens culinaris*), and soybean (*Glycine max*) are the major field crops. The major vegetable crops are Knol-khol (*Brassica oleracea* var. *gongylodes*), cabbage (*B. oleracea* var *capitata*), cauliflower (*B. oleracea* var. *botrytis*), turnip *Brassica rapa*), radish (*Raphanus sativus*), carrot (*Daucus carota* var. *sativa*), onion (*Allium cepa*), pea (*Pisum sativum*), spinach (*Spinacia oleracea*), garlic (*Allium sativum*), tomato (*Solanum lycopersicum*), chillies (*Capsicum annuum var. acuminatum*), capsicum (*Capsicum annuum*), French bean (*Phaseolus vulgaris*), brinjal (*Solanum melongena*), bottle gourd (*Lagenaria siceraria*), cucurbits (*Cucumis melo, C. sativus*), bitter gourd (*Momordica charantia*), pumpkin (*Cucurbita maxima, C. pepo*), *Brassica campestris, B. oleracea)* and potato (*Solanum tuberosum*). Fruits such as apple (*Malus pumila*), peach (*Prunus persica*), apricot (*P. armeniaca*), plum (*P. domestica*), almond (*P. amygdalus*), common plums (*Spondias* spp), etc., are the major fruit crops. Floriculture is also fast emerging as an important cash generating activity of the production systems in certain areas. Fruit orchards of several species are found in the hills of Himachal Pradesh, Jammu & Kashmir, and Uttrakhand. The fruit trees like plum, peach, apricot, etc., are grown up to 1500 m elevation. Apple orchards are found above 1500 m elevation. The terraced agricultural fields are in the form of narrow strips whose width varies from 2 to 5 m. Plantations of trees on agricultural croplands were not common in the past as enough forests were available in the vicinity, however, after clearing the forests for plantation of fruit trees as orchards in the hills during the last 4–5 decades has created acute shortage of firewood and fodder and has compelled the farmers to grow trees on their farmlands as a part of their farming systems to meet their daily need of fuel, fodder, and timber.

Indigenous Agroforestry Systems

Various traditional agroforestry system occurring in different agro-climatic zones of Northwestern Himalayan hill states along with their functional units are given in the Table 2.4.

Some Important Indigenous/Traditional Systems of the Region

Homesteads (*Kyaroo*)

A homestead (*kyaroo)* is an operational farm unit in which a number of tree species for fodder, timber, and fuelwood are raised along with livestock, poultry, and/or fish mainly for the purpose of satisfying the farmers' basic needs. It is locally called as *kyaroo* in Kangra, Hamirpur, and Jammu areas, but in general it is developed and managed by every farmer in the region to meet their day-to-day requirements. In a *kyaroo*, multiple crops are present in a multitier canopy configuration. The fodder trees such as *Celtis australis* (Khirak), *Bahaunia variegata* (Kachnar), *Grewia optiva* (Beul), and bamboo species particularly major bamboo (*Dendrocalamus hamiltonii*) and *lathi* bamboo (*D. strictus*) for both timber and fodder are managed in the upper storey, whereas middle storey is constituted of bushes like medicinal *Adhatoda vasica*, *Vitex negundo*, etc. The fruit trees such as pear, plum, lemon and citrus, etc., are grown for domestic use.

During the rainy season cucurbits (vines) are grown along with taro (*Colocasia esculanta*), elephant foot yam (*Dioscoria* spp), and turmeric (*Curcuma domestica*). However, wide variation in the intensity of tree cropping is noticeable in different places. This is generally attributed to the differences in socioeconomic conditions of the households and their response to externally determined changes, particularly prices of inputs and products, dependence on land and tenurial conditions, etc. (Verma 1998).

Plantation Crop Combination

Plantation crops play a major role in national economics because these generate value added goods for the international markets. The important plantation crop of the Himalayan region is tea. Traditionally, tea is grown on waste and marginal lands in association with indigenous forest tree species. In Himachal Pradesh, tea gardens in Kangra, Palampur, and Baijnath valleys are managed under the canopy of *Albizia chinensis*, which not only nurses the tea plants by fixing the atmospheric nitrogen in its roots but also provides shade for the development and maintenance of new tenders. The leaf litter of *Albizia* trees also adds nutrients to the soil and during lean period the trees are used for fodder.

Bamboo Groves

The cultivation of bamboo (*Dendrocalamus hamiltonii, D. structus,* and *Bambusa nutans*) is a common practice in agricultural holdings alongside the streams and irrigation/drainage channels and on the agriculture field along *Nalas* and *Choes.* Bamboos are extensively used in building small farmhouses, cow sheds, piggery enclosures, baskets, mates, fishing rods, hookah pipes, and various household items for daily use (Fig. 2.2), string making, and also used as water conveyers for irrigation/drainage system. Bamboo leaves serve as an excellent winter fodder for cattle. Bamboo stumps/culms also protect the water channels from erosion. This system is limited only to the high rainfall subtropical and mid-hill moist areas where sufficient water is available to grow bamboo, e.g., Palampur, Hamirpur, Una, and Bilaspur areas of Himachal Pradesh; Jammu area of Jammu and Kashmir; and Dehradun area of Uttrakhand are well known for bamboo groves (Verma 1998).

Table 2.4 Traditional agroforestry systems in North western Himalayan region

Zone	System	Functional units
(A) Jammu and Kashmir		
(i) Kashmir valley		
Zone I 1000–2000 m amsl	Agri-silviculture in plains (irrigated)	Forest trees: *Populus deltoides, Populus nigra, Salix alba, Robinia pseudoacacia*, *Ailanthus altissima, Aesculus indica,* etc.
		Crops: Knol-khol, cabbage, cauliflower, turnip, radish, carrot, onion, pea, spinach, garlic, tomato, chillies, capsicum, French bean, bottle gourd, cucurbits, bitter gourd, pumpkin, potato, etc.
Zone II 2000–2500 m amsl	Agri-silviculture on slopes (mid-hills or foot hills of mountains)	Forest trees: *Robinia pseudoacacia, Ailanthus altissima, Aesculus indica, Populus nigra, Salix alba,* etc.
		Crops: Maize, mustard, carrot, turnip, radish, etc.
Zone III >2500 m amsl	Boundary plantation (Low lying area)	Forest trees: *Populus deltoides, Populus nigra, Salix alba, Aesculus indica,* etc.
		Crops: Paddy, oats, mustard, wheat, etc.
	Forest & fruit trees- based cropping systems (High altitude, rainfed)	Forest trees: *Populus ciliata, Populus nigra, Salix alba, Robinia pseudoacacia, Ailanthus altissima, Aesculus indica,* etc.
		Horticultural trees: Pomegranate (*Punica granatum),* walnut, apricot, peach, pear, apple, almond, etc.
		Crops: Tomato, brinjal, chillies, pea, brassica, cauliflower, cabbage, radish, turnip, onion, oats, wheat, etc.
	Fruit and forest trees based pastoral systems (on the slopes, rainfed)	Forest trees: *Populus deltoides, Populus nigra, Salix alba, Robinia pseudoacacia, Ailanthus altissima, Aesculus indica,* etc.
		Horticultural trees: *Punica granatum*, walnut, apricot, peach, pear, apple, almond, etc.
		Grasses: Oats, *Festuca pratense, Trifolium* spp., *Dactylis glomerata,* etc.
	Homesteads	Forest trees : *Populus deltoides, Populus nigra, Platanus orientalis, Salix alba, Robinia pseudoacacia, Ailanthus altissima, Aesculus indica,* etc.
		Fruit trees: *Malus domestica* (apple), *Juglans regia* (walnut), *Pyrus communis* (pear), *Prunus armeniaca* (apricot), *Prunus amygdalus* (almond), peach (*P. persica*), Cherry (*Prunus avium*) Pistachio nut *(Pistacia vera),* pomegranate (*Punica granatum*), etc.
		Vegetable crops: Cabbage, turnip (*Brassica rapa*), radish, spinach, carrot, onion, peas, etc.

(continued)

Table 2.4 (continued)

Zone	System	Functional units
(ii) Jammu		
Zone I <1000 m amsl Subhumid	Agri-silviculture (subhumid)	Forest trees *: Acacia nilotica, Ailanthus excelsa, Albizia lebbek, Grewia optiva, Bauhinia variegata, Ziziphus mauritiana, Dalbergia sissoo, Dendrocalamus strictus, D. hamiltonii, Melia Azedirach, Morus alba, Toona ciliata, Populus deltoides, Sesbania aegyptica, Leucaena leucocephala*
		Crops: Wheat, maize, pulses, millets, medicinal, and aromatic plants
Zone II and III 1000–2500 m amsl High hill temperate zone	Agri-silviculture	Forest Trees: *Populus ciliata, Salix alba, Robinia pseudoacacia, Alnus nepalensis, Quercus leucotrichophora, Ulmus wallichiana, Celtis australis,* etc.
		Crops: Wheat, oat, maize, medicinal and aromatic plants, *Dioscorea* spp.
	Fruit and forest trees-based cropping systems as well as pastoral systems	Horticulture trees : *Mangifera indica* (mango), *Litchi chinensis* (litchi), *Psidium guajava* (guava), *Carica papaya* (papaya), *Emblica officinalis* (aonla), *Citrus* spp. (lemon, kagzi lime, orange, chakotra, galgal, mosumbi), etc.
		Forest trees : *Populus deltoides* (poplar), *Dalbergia sissoo* (shisham), *Albizia lebbek* (siris), *A. chinensis* (black siris), *Ulmus villosa* (Elm), *Toona ciliata* (toon), *Acacia catechu* (khair), *Olea ferruginea, Anogeissus latifolia* (dhawda), *Grewia optiva* (beul), *Morus leavigata* (Toot), *Bauhinia variegata* (kachnar), *Santalum album* (Chandan), *Pinus roxburghii* (Chir pine), *Terminalia* spp., *Emblica officinalis* (aonla), *Sapindus mukorossi* (soap nut), Bambusa species, etc.
		Crops: Wheat, maize, soybean, *Cicer arietinum* (gram), *Lens esculenta* (lentil), *Brassica* spp. (mustard), *Vigna mungo* (urd), *Vigna umbellata* (rice-bean), *Cajanus cajan* (arhar), *Pisum sativum* (pea), *Abelmoschus esculentus* (okra), *Capsicum frutescens* (capsicum), *Phaseolus vulgaris* (French bean), *Brassica oleracea* (cauliflower), *Brassica capitata* (cabbage), etc.
		Grasses: *Setaria, Panicum,* Napier, etc.

(continued)

Table 2.4 (continued)

Zone	System	Functional units
(B) Himachal Pradesh		
Low hills subtropical zone <1000 m amsl	Fruit and forest trees-based cropping systems as well as pastoral systems	Forest trees: *Aesculus indica*, *Alnus nitida, Betula, Salix, Quercus leucotrichophora (*Ban oak*)*, Q. *semecarpifolia* (Kharsu oak)*, Q. dilatata* (Moru oak), *Rhododendron arboretum* (Buransh), *Abies pindrow* (Himalayan fir), *Picea smithiana* (Himalayan spruce), *Pinus wallichiana, Pinus roxburghii, Cedrus deodara* (Deodar), *Ulmus wallichiana*, *Myrica nagi* (Kafal), Hill bamboo, etc.
		Horticulture trees: *Malus domestica* (apple), *Juglans regia* (walnut), *Pyrus communis* (pear), *Prunus armeniaca* (apricot), *Prunus amygdalus* (almond), Pistachio nut, etc.
		Crops: Wheat, maize, barley, *Elusine coracana* (mandua), pearl millet, *Pisum sativum* (pea), *Phaseolus vulgaris* (French bean), cauliflower, tomato, cabbage, *Amaranthus caudatus* (ramdana), potato, rice-bean, *Fagopyrum esculentum* (buckwheat), etc.
		Grasses: *Chrysopogon, Eragrostis, Apluda,* etc.
Subtemperate mid-hills (1000–1500 m amsl)	Fruit and forest trees-based cropping systems as well as pastoral systems	Forest Trees: Populus species, Juniperus spp., *Pinus gerardiana* (chilgoza pine), *Hippophae, Betula, Robinia pseudoacacia, Salix,* etc.
		Horticulture trees: *Malus pumila* (apple), *Prunus armeniaca* (apricot), almond, Pistachio nut, etc. Crops: Wheat, barley, *Amaranthus* spp, potato, buckwheat, etc.
		Grasses:*, Agropyron semicostatum, Eragrostis, Deschampsia cespitosa, Helictotrichon, Poa,* etc.
Temperate high hills (1500–2500 m amsl)	Fruit and forest trees-based cropping systems as well as pastoral systems	Forest Trees: Populus species, *Juniperus* spp., *Pinus gerardiana* (chilgoza pine), *Hippophae, Betula, Robinia pseudoacacia, Salix,* etc.
		Horticulture trees: *Malus pumila* (apple), *Prunus armeniaca* (apricot), almond (*P. amygdalus*), Pistachio nut (*Pistacia vera*), etc.
		Crops: Wheat, barley, *Amaranthus,* potato, buckwheat, etc.
		Grasses:*, Agropyron semicostatum, Eragrostis, Deschampsia cespitosa, Helictotrichon, Poa,* etc.

(continued)

Table 2.4 (continued)

Zone	System	Functional units
Dry temperate zone (>2500 mamsl)	Fruit and forest trees based cropping systems	Forest trees: *Eucalyptus*, *Populus deltoides* (poplar), *Anthocephalus cadamba* (kadam), *Dalbergia sissoo (*shisham), *Tectona grandis* (teak), *Toona ciliata* (toon), *Acacia catechu* (khair), *Holoptelea integrifolia* (kanju), *Adina cordifolia* (haldu), etc.
		Horticulture trees: *Mangifera indica* (mango), *Litchi chinensis* (litchi), *Psidium guajava (*guava), *Artocarpus integerifolia* (jack fruit), *Carica papaya* (papaya), *Emblica officinalis* (aonla), *Citrus* sp. (lemon, kagzi lime, orange, chakotra, galgal, mosumbi), etc.
		Crops: Wheat, maize, rice, *Glycine max* (soybean), *Cicer arietinum* (gram), *Lens esculenta* (lentil), mustard, *Saccharum officinarum* (sugarcane), *Curcuma domestica* (turmeric), *Phaseolus mungo* (urd), *P. aureus* (mung), *Vigna umbellata* (rice-bean), *Cajanus cajan* (arhar), *Pisum sativum* (pea), *Abelmoschus esculentus* (okra), garlic, onion, *Capsicum frutescens* (capsicum), *Phaseolus vulgaris* (French bean), cauliflower, *Brassica oleracea* var. *capitata* (cabbage), etc.
(C) Uttrakhand		
Tarai and Bhabar, submountain and low hills (up to 1000 m amsl)	Fruit and forest trees-based cropping systems as well as pastoral systems	Forest trees: *Aesculus indica*, *Alnus nitida, Betula, Salix, Quercus leucotrichophora*, *Q. semecarpifolia, Q. dilatata*, *Fraxinus micrantha, Rhododendron arboretum*, *Populus ciliata, Taxus baccata, Abies pindrow*, *Cedrus deodara*, *Myrica nagi*
		Horticulture trees: *Malus pumila* (apple), *Juglans regia* (walnut), *Pyrus communis* (pear), *Prunus armeniaca* (apricot), *Prunus amygdalus* (almond), Pistachio nut, etc.
		Crops: Wheat, maize, barley, *Elusine coracana* (mandua), *Paspalum* spp. (Jhingora), pearl millet, pea, French bean, cabbage, *Amaranthus caudatus* (ramdana), potato, rice-bean, buckwheat, etc.
		Grasses: *Eragrostis* spp., *Bromus inermis, Festuca arundinacea, Dactylis glomerata, Koeleria cristata , Cymbopogon distans, Chrysopogon royleanus, Danthonia cachemyriana, Digitaria decumbense, Festuca arundinacea, F. pratense, Phleum repens, Setaria anceps, Chrysopogon montanus, Lolium multiflorum, Panicum clandestinum, Chloris gayana, Lolium rigidum, Arundinella nepalensis, Phleum pratense, Poa annua,* etc.

(continued)

Table 2.4 (continued)

Zone	System	Functional units
Subtemperate mid-hills (1000–1500 m amsl)	Fruit and forest trees-based cropping systems as well as pastoral systems	Forest trees: *Hippophae* spp., *Betula, Salix,* etc.
		Horticulture trees: *Malus pumila* (apple), *Prunus armeniaca* (apricot), almond (*P. amygdalus*), Pistachio nut, etc.
		Crops: Wheat, barley, potato, buckwheat etc.
		Grasses: *Dichanthium* spp., *Koeleria cristata, Calamagrostis emodensis, Festuca lucida, Brachypodium sylvaticum, Trisetum spicatum, Andropogon tristis, Phleum repense, Agropyron semicostatum, Eragrostis* spp., *Deschampsia cespitosa, Helictotrichon virescens* and *Dactylis glomerata*, etc.
Temperate high hills (1500–2500 m amsl)	Forest and fruit trees-based cropping and pastoral systems	Forest trees: *Aesculus indica* (pangar), *Alnus nitida*, *Betula*, *Salix*, *Quercus leucotrichophora* (Banj), *Q. semecarpifolia* (kharsu), *Q. dilatata* (moru), *Fraxinus micrantha*, *Rhododendron arboretum* (Buransh), *Populus ciliata* (Poplar), *Taxus baccata* (thuner), *Abies pindrow* (raga), *Cedrus deodara* (deodar), *Myrica esculenta* (kaiphal)
		Arable crops: Wheat (Kaiphal), maize, barley, *Elusine coracana* (mandua), *Paspalum* sp (Jhingora), pearl millet, pea, French bean, cabbage, *Amaranthus caudatus* (ramdana), potato, rice-bean, *Fagopyrum esculentum* (buckwheat)
		Horticultural trees: *Malus pumila* (apple), *Juglans regia* (walnut), *Pyrus communis* (pear), *Prunus armeniaca* (apricot), *Prunus amygdalus* (almond), Pistachio nut Grasses: *Aragrostis* spp, *Bromus inermis, Festuca arundinacea*, *Dactylis glomerata*,, *Kobretia* sp, *Cymbopogon distans*, *Chrysopogon royleanus*, *Danthonia cachemyriana*, *Digetaria decumbense*, *Festuca arundinacea*, *F. pratense*, *Phleum repens*, *Setaria anceps*, *Chrysopogon orientalis*, *Lolium multiflorum, Panicum cladystymum*, *Chloris gayana*, *Lolium vigidum*, *Arundinella nepalensis*, *Phleum pratense*, *Poa annua*
Dry temperate zone (>2500 m amsl)	Agri-silviculture Horti-silviculture Silvi-pastoral	Forest trees: Species of *Hippophae*, *Betula*, *Salix*, etc.
		Arable crops: Wheat, barley, amaranthus, potato, buckwheat
		Horticultural trees: *Malus pumila* (apple), *Prunus armeniaca* (apricot), almond, Pistachio nut Grasses: *Dichanthium annulatum*, *Koeleria cristata*, *Calamagrostis emodensis*, *Festuca lucida*, *Brachypodium sylvaticum*, *Trisetum spicatum*, *Andropogon tristis*, *Phleum repense*, *Agropyron semicostatum*, *Agrostis munroana*, *Deschampsia caespitosa*, *Helictotrichon virescens*, and *Dactylis glomerata*

Sources Tewari et al. (2007), Verma et al. (2007), Mughal and Khan (2007), Saleem and Gupta (2007)
For scientific names of crops see text just before the table

Fig. 2.2 Handmade bamboo artifacts for sale in the market of Himachal Pradesh

Sea-Buck-Thorn Based Agroforestry Systems in Cold Desert Areas

Sea-buck-thorn (*Hippophae rhamnoides*) is well known for its environmental benefits, desertification control, and land reclamation in fragile cold arid ecosystems. It fixes nitrogen by symbiotic association with microorganisms, e.g., *Frankia* to the tune of about 180 kg $ha^{-1}yr^{-1}$. Its plantation serves as windbreaks and also checks pedestrian traffic. Traditionally, it is planted around agricultural fields for protection of crops against stray animals and as a fuel wood because it is a potential energy plant in the region. The calorific value of dry sea-buck-thorn wood is 4,785 calories kg^{-1}. It is fast growing shrub and can stump every 3–5 years and hence reduce pressure on other native woody plants. In Ladakh region, sea-buck-thorn (*Hippophae*) is harvested from wild at large scale (Fig. 2.3) and fruit pulp was sold worth of INR 14 million in 2007 for making fruit juices as a trade name "Leh berry" which has medicinal value. Its plantation/cover area accounts for less than 5 % of its potential of the region and if fully utilized the shrub can change the entire economy of the region (Stobdan et al. 2008).

Research and Development Initiatives in Agroforestry

Identification of Multipurpose Tree Species

Surveys were conducted in different agro-climatic zones of the states for the identification of different multipurpose tree species (MPTs) grown on farmers fields and adjoining forest areas and more than 60 % land is found under the jurisdiction of forest department for their livelihood subsistence. The farmers keep the trees for fuel, fodder, and timber. The important MPTs with their climatic zones and altitudinal distribution alongwith method of planting and uses are given in Table 2.5.

Many trees such as *Grewia optiva* are frequently used in cropping systems by the farmers. Progressive farmers grow vegetables such as tomato (*Solanum lycopersicum*), brinjal (*Solanum melongena*), chillies (*Capsicum annuum*), etc., as remunerative crops along with trees (Fig. 2.4)

Fig. 2.3 Seabuck-thorn (*Hippophae rhamnoides*) fruits harvested by the local people for sale and domestic purposes. Inset showing the fruit branch of seabuckthorn

Fodder Values of Important Trees and Grasses

The fodder values of promising fodder trees and grasses have been studied for meeting farmers demand as well as to understand their preference to grow specific tree on their farm lands and presented in Table 2.6.

Soil Amelioration Potential Through Agroforestry

Northwestern Himalayan region is most important ecosystem of the country to meet the irrigation potential of the Indo-Gangetic plain region which is called as "Food Ball of India" as already stated. They are characterized by undulating barren hill slopes, undulating agriculture fields and erratic rainfall pattern. The hilly terrain is subjected to runoff and soil loss of varying degrees. The geological formation of Himalayas is young in age and very weak, having scanty vegetation in some of the areas as a result of which the area is subjected to high erosion. Biotic pressure is also important reason for causing soil degradation. The dispersion ratio is used to assess the erosion behavior of the soils. Kumar et al. (2002) reported that dispersion ratio was comparatively higher under cultivated lands (18.50–21.82) followed by orchards (13.25–14.46) and lowest under forests (11.64–12.93). The erosion ratio also followed the same trend (Table 2.7) for which the vegetative cover could be the reason.

More the vegetation higher the organic carbon content which results in higher water stable aggregates. Agroforestry practices consist of at least one woody component so it results in more addition of organic matter and increase in the organic carbon content. The canopy cover which increases over the unit area plays important role to limit the soil erosion by varying agents like water, wind, etc.

Barren lands recorded very high soil loss (86.05 t ha^{-1} yr^{-1}) followed by intensively cultivated areas (58.87 t ha^{-1} yr^{-1}), and fruit tree—based cropping system (18.27 t ha^{-1} yr^{-1}), degraded forests (17.76 t ha^{-1} yr^{-1}), and lowest soil loss (3.46 t ha^{-1} yr^{-1}) was recorded in dense forests (Table 2.8). The vegetation protects the soil against impact of falling rain drops, increases the roughness of soil surface, reduces the speed of runoff, binds the soil mechanically, and improves the physical, chemical, and biological properties of soil. Alternative land uses such as forest and fruit trees—based cropping systems on unstable slopes reduce losses and generate additional income to the farmers and have sufficient biomass for nutrient recycling (Sharma et al. 2002).

The silvopastoral and agri-silviculture systems provided best mechanism for conservation in Shiwalik hills. The soil loss and runoff under

Table 2.5 Multipurpose tree species (MPTs) of Northwestern Himalayan region

S. No.	Name of species	Climatic zone Altitudinal range (m amsl)	Method of planting	Uses
1.	*Abies pindrow*	2000–3500	SL	Timber, packing cases, plywood, pulp, and paper
2.	*Acacia auriculaeformis*	<1000	DS, SL	Timber, fuel, ornamental
3.	*A. catechu*	<1200	DS, SL	Fodder, timber, fuel, katha and cutch, gum, soil conservation
4.	*A. nilotica*	<700	DS, SL	Fuel, timber, tannin, gum, fodder
5.	*Acer acuminatum*	2400–2800	SL	Fuel, timber
6.	*A. caesium*	2400–2800	SL	Fuel, timber
7.	*A. pictum*	2400–2800	SL	Fuel, timber
8.	*A. oblongum*	1000—1800	DS,SL	Timber, agricultural implements
9.	*Aegle marmelos*	<1000	DS,SL	Fuel, fruit, gum, bark, and fruit medicine
10.	*Aesculus indica*	1200–2400	SL,DS	Timber, fodder, fruit, ornamental
11.	*Ailanthus altissima*	1500–2400		Timber, packaging cases, fodder
12.	*Albizia chinensis*	700–1200	DS, SL	Timber, fodder, fuel and shaded tree in tea gardens
13.	*A. lebbek*	700–1200	DS, SL	Timber, fodder, medicinal, fuel
14.	*A. procera*	110–700	DS, SL	Fodder, fuel, and timber
15.	*Alnus nepalensis*	700–1200	DS, SL	Timber, fuel, soil conservation
16.	*A. nitida*	700–1200	DS, SL	Timber, fuel, soil conservation
17.	*Anogeissus latifolia*	200–700	SL	Fuel and fodder
18.	*Artocarpus lakoocha*	200–500	DS, SL	Timber, fruit, fodder, Vegetables
19.	*Azadirachta indica*	<500	DS, SL	Timber, bark and seed—medicine, insecticidal, fertilizer
20.	*Bambusa balcoa*	<1000	Rhizomes, offsets	Constructional purposes, paper and pulp, cottage industry
21.	*B. tulda*	<1000	Rhizomes, offsets	Constructional purposes, mats, basket, young shoot pickled, and eaten
22.	*Bauhinia variegata*	<1200	SL, DS	Cherry gum, bark-dye and medicine, fodder, fuel, flower buds vegetables
23.	*Betula alnoides*	>3000	SL, DS	Plywood, furniture, tool handles
24.	*B. utilis*	>3000	SL	Bark papery (Bhojpatra), timber, fodder
25.	*Bombax ceiba*	<1200	DS, SL, BC	Match industry, plywood
26.	*Butea monosperma*	<500	DS, SL	Fodder, fuel, lac and dye making
27.	*Carpinus wiminea*	>2000	SL	Ornamental, bobbin manufacture
28.	*Cassia fistula*	<800	DS, SL	Fuel, timber
29.	*Celtis australis*	>700	SL, BC, DS	Timber, fuel, fodder, fruit-edible and also of medicinal value, sports goods, utensils
30.	*Cordia myxa*	<700	DS, SL	Kernel—medicine, timber for agriculture implements, pickle
31.	*Coriaria nepalensis*	1200–2500	SL	Boxwood, tannin, food for silk worm

(continued)

Table 2.5 (continued)

S. No.	Name of species	Climatic zone Altitudinal range (m amsl)	Method of planting	Uses
32.	*Dalbergia sissoo*	100–1200	DS, SL	Timber, furniture, sleepers, plywood, fuel, fodder
33.	*Dendrocalamus hamiltonii*	500–1800	DS, Rhizomes	Paper pulp, vegetable—young shoots, constructional
34.	*D. strictus*	300–1200	DS, SL, Rhizomes	Paper making, cottage industries, mathematical instruments
35.	*Emblica officinalis*	100–1000	DS,SL	Fruit, hair dyes, fodder, tannin, timber, fuel, myrobalan, medicine, hair oil
36.	*Erythrina suberosa*	400–1000	BC, SL	Light timber, cork, packing cases, hosts for black pepper, ornamental
37.	*Eucalyptus camaldulensis*	<1800	SL	Timber, charcoal, fuel, gum-medicinal and apiculture (Honey bee) flora
38.	*E. tereticornis*	<1200	SL	Timber, paper pulp, plywood, fuel, essential oil, honey bee flora
39.	*Ficus palmata*	<1000	SL, BC	Ornamental, fodder, edible fruits
40.	*Grewia elastica*	<500	SL	Ornamental, timber, toy making, fuel, shade tree
41.	*G. optiva*	500–1500	SL	Timber-cot frames, fiber, fodder, fuel wood
42.	*Hippophae rhamnoides*	>3000	DS, BC	Medicinal, fuel, soil conservation, and fodder
43.	*Juglans regia*	>2000	DS, SL	Timber—furniture and carving, gun-stocks, fruits
44.	*Juniperus communis*	>3000	DS, SL	Volatile oil, medicinal, resin, wad, esters
45.	*J. polycarpus*	>3000	DS, SL	Timber, walking sticks, drinking cups, fuel and charcoal, medicinal, essential oil
46.	*Lagerstroemia speciosa*	<1000	SL	Timber-constructional purposes, furniture, agricultural implements, telegraph poles, railway sleepers, medicinal, fodder
47.	*Lannea coromandelica*	<800	DS,SL, BC	Matchwood, pulpwood, gum and brushwood, soil conservation
48.	*Leucaena leucocephala*	<1200	DS, SL	Paper pulp, fodder, light timber, fuel
49.	*Mangifera indica*	<600	SL	Edible fruits, fatty oil, plywood, shoe heels
50.	*Melia azedarach*	<2000	DS, BC,SL	Box planks, fuel wood, paper pulp, medicinal
51.	*Moringa oleifera*	<500	BC, DS	Fruits-edible, medicinal, fodder
52.	*Morus alba*	<1200	BC, DS, SL	Fruits-edible, timber, sports goods, fodder
53.	*M. serrata*	1500–2500	BC,DS	Furniture, toys, sports goods, fodder
54.	*Ougeinia oojeinensis*	<800	BC,SL, DS	Cart, carriage, building construction, fodder agricultural implements, and edible fruits
55.	*Picea smithiana*	>2200–3000	SL	Planking, general filling and joinery, packing cases

(continued)

Table 2.5 (continued)

S. No.	Name of species	Climatic zone Altitudinal range (m amsl)	Method of planting	Uses
56.	*Pinus roxburghii*	<1500	SL	Timber, resin, pulpwood
57.	*P. wallichiana*	<1500–2500	SL	Timber, resin, pulpwood
58.	*Pithecellobium dulce*	<400	BC,DS	Packing cases, fuel, agricultural implements, fruits-edible, yield fatty oil, fodder
59.	*Platanus orientalis*	1500–2500	SL, BC	Ornamental, fuel, cheap timber
60.	*Populus alba*	>2500	BC,SL	Matchwood, pulpwood, light timber, fuel
61.	*P. ciliata*	1500–2500	RS, RC,BC	Matchwood, pulpwood, light timber, fuel, fodder
62.	*P. deltoides*	<1200	BC	Matchwood, pulpwood, light timber, fuel, packaging cases
63.	*P.euphratica*	>2500	B0C	Matchwood, pulpwood, light timber, fuel, and fodder
64.	*P. nigra*	>2500	BC	Matchwood, pulpwood, light timber, fuel, and fodder
65.	*Prunus domestica*	>1500	SL	Fruits-edible, fodder, timber, fuel
66.	*P. padus*	>1200	SL	Fruits-edible, fodder, timber, fuel
67.	*Psidium guajava*	<700	SL	Fruits-edible, wood engraving, spear handles, instruments, and lac turnery, medicinal
68.	*Punica granatum*	600–1200	BC, SL	Fruits-edible, ornamental, fuel wood, fodder
69.	*Quercus dilatata*	2500–3000	BC	Fuel, fodder
70.	*Q. leucotrichophora*	1500–2500	DS	Fuel, fodder
71.	*Q. semecarpifolia*	2500–3500	BC	Fuel, fodder
72.	*Salix alba*	<700	BC	Cricket bats, matchwood, tool handles, fuel, fodder
73.	*S. flabellaria*	>3000	BC	Fuel, fodder
74.	*S. fragilis*	>3000	BC	Light timber, charcoal for gun powder, fuel, soap (Saponine)
75.	*Santalum album*	<1000	DS,RS, SL	Fragrant heartwood, sandal oil, carving work, medicinal, agarbatties, perfumery
76.	*Shorea robusta*	<600	DS, SL	Timber, constructional purposes, plywood, paper pulp in mixture
77.	*Syzygium cuminii*	<600	DS, SL, ST, BC	Fruit-edible and medicinal, timber plywood, tools and implements, fuel, fodder
78.	*Terminalia bellirica*	<700	SL, DS, ST	Timber, pulp, plywood, fruit (myrobalan) medicinal, fodder
79.	*T. chebula*	<700	SL, DS	Fruits (myrobalan), medicinal, timber
80.	*Toona ciliata*	<2000	DS, SL	Timber, plywood, ornamental, fodder
81.	*Ziziphus muritiana*	<500	DS,SL, BC	Fruits, fuel, tannin, medicinal, fodder

DS Direct sowing, *SL* seedling (entire planting), *BC* Branch cutting *RC* Root cutting, *RS* Root suckers, *ST* Stump planting

Source UHF (1987), Bhatt et al. (2010), Dalvi and Ghosh (1982)

Fig. 2.4 Tomato (*Solanum lycopersicum*) as inter-crop with *Grewia optiva* trees

Eucalyptus tereticornis with bhabar grass (*Eulaliopsis binata*) reduced to 0.07 t ha^{-1} and 0.05 % in comparison to 5.65 t ha^{-1} and 23.0 % under cultivated fallow and 2.69 t ha^{-1} and 20.50 % under *Sesamum indicum—Brassica campestris* systems, respectively. Thus, tree-based systems were found to be very useful in Shiwalik region where erosion is a major cause of soil degradation and nutrient depletion (Grewal 1993). During the 9-year-study period, the average annual monsoon rainfall was about 1000 mm and it caused 347 mm runoff and 39t ha^{-1} soil loss due to erosion every year from fallow plots. The runoff and soil loss were reduced by 27 and 45 %, respectively by contour cultivation of maize (*Zea mays*). Contour tree-rows of *Leucaena leucocephala* hedges reduced the runoff and soil loss by 40 % and 48 %, respectively over the maize plot (reducing soil loss to 12.5 t ha^{-1}). This reduction in erosion was primarily due to the barrier effect of trees or hedgerows and micro-terraces formed through sediment deposition along the contour barriers. Such vegetative measures, that are productive while being protective, offer viable alternative for erosion control in areas with gentile slopes of the valley region. High density block plantations of eucalyptus and leucaena almost completely controlled the erosion losses and can be recommended for steeper slopes that are vulnerable to heavy erosion (Narain et al. 1998).

The soils were analyzed for different nutrient status in the 20 years old plantation of fodder trees in subtropical humid zone of Himachal Pradesh and it was observed that organic carbon (OC) and available N, P, K, and Ca increased significantly in each type of block plantation. The highest OC contents (2.75 %) were observed under *Ulmus villosa* and *Albizia stipulata* syn. *A. chinensis* (2.74 %). The highest available nitrogen kg ha^{-1} was under *Albizia stipulata* and *Dalbergia sissoo*, i.e., 458 and 459 kg ha^{-1}, respectively; available P in *Grewia optiva* (459 kg ha^{-1}) and exchangeable Ca in *Dalbergia sissoo* plantation (5880 kg ha^{-1}), whereas pH was observed near to neutral and EC was almost same as in the control in all the plantations (Table 2.9). *Albizia stipulata, Bauhinia variegata, Bombax ceiba, Celtis australis, Dalbergia sissoo, Grewia optiva, Robinia pseudoacacia, Sapindus mukorossi, Toona ciliata, Quercus luecotricophora,* and *Ulmus villosa,* etc., are the important tree species which the farmers of the western Himalayan region have grown on their farmlands to supplement their fodder and fuelwood needs. There is no doubt in some of these species also render benefit to the farming community indirectly, i.e., through atmospheric nitrogen fixation, addition of organic matter in the form of litter fall and also conservation of soil and water, the most important natural resources for the livelihood.

Table 2.6 Fodder quality of promising agroforestry fodder trees and grasses of Northwestern Himalayan region

Fodder trees	CP %	CF %	Ether extract %	Ash %	Ca %	P %
(A) Lower and mid-hill (900–1800 m amsl)						
Albizia chinensis	15.08	31.64	4.39	5.50	1.02	0.20
Albizia lebbeck	16.81–26.50	26.47–37.59	2.85–4.68	7.11–11.54	2.02	0.14
Anogeissus latifolia	7.45–11.48	16.38–24.15	2.68–4.41	8.68–10.93	3.03	0.34
Bamboos	12.00–19.00	12.00–20.00	2.50–4.00	11.98–19.04	0.50–1.12	0.05–0.26
Bauhinia variegata	10.73–15.91	25.28–32.97	1.33–3.93	6.37–12.31	2.40	0.22
Celtis australis	14.47–15.33	19.45–21.45	2.54–5.62	11.66–17.81	4.87	0.18
Ficus roxburghii	12.28–13.35	7.71–17.79	4.49–4.65	9.42–15.52	1.31–2.19	0.17–0.22
Grewia optiva	15.60–19.05	18.88–22.12	2.17–6.70	9.60–14.30	3.20	0.21
Leucaena leucocephala	24.20	13.30	4.40	10.80	1.98	0.27
Morus alba	15.00–27.64	9.07–15.27	2.30–8.04	14.32–22.87	2.43	0.24
Pittosporum floribundum[a]	14.70	10.25	3.81	9.54	2.80	0.20
Grasses						
Avena fatua	6.50	35.70	1.80	8.90	0.80	0.10
Dichanthium annulatum	2.08	39.60	–	0.50	0.50	–
Euchlaena maxicana	4.47–11.99	19.57–32.20	1.20–2.34	–	0.65–0.91	0.16–0.28
Medicago sativa	19.90	29.51	1.81	14.10	2.80	0.74
Panicum maximum	2.8–16.1	41–57	28–34	–	0.32–0.76	0.35–0.80
Pennisetum hybrid (Napier)	10.20	30.50	2.10	16.20	0.50	0.40
Pennisetum pedicellatum	6.50	35.80	3.20	14.40	0.40	0.30
Sorghum bicolor	7.75	32.36	1.73	8.55	-	–
Trifolium alexandrinum	15.80–26.70	14.90–28.50	1.40–3.00	12.90–16.00	1.48–2.58	0.18–0.31
Zea mays	6.74	85.95	2.09	8.15	–	–
(B) Higher Hills (1800 m amsl and above)						
Fodder trees						
Celtis australis	14.47–15.33	19.45–21.45	2.54–5.62	11.66–17.81	3.47–4.87	0.18
Morus alba	15.00–27.67	9.07–15.27	2.30-8.04	14.32-22.87	2.42-4.71	0.23-0.97
Morus serrata	14.00–22.00	9.07–14.27	2.30–6.00	13.32–22.87	2.40–4.60	0.20–0.95
Populus ciliata	10.00–12.00	22–26	4.00-8.00	8.00-11.00	–	–
Quercus dilatata	9.56	29.06	4.52	5.11	0.17	0.35
Q. glauca	9.62	29.04	4.14	7.6	1.87	0.23
Q. leucotrichophora	10.20–11.42	31.34	3.53–4.84	5.13–6.43	0.90–1.65	0.11–0.15
Robinia pseudoacacia	14–25.5	46.50	3.30	6.09	1.17	–
Salix alba	12.00–17.00	33.35	4.00-5.00	7.00–11.00	–	–
Grasses						
Dactylis glomerata	18.80	33.20	–	8.96	–	–

(continued)

Table 2.6 (continued)

Fodder trees	CP %	CF %	Ether extract %	Ash %	Ca %	P %
Festuca arundinacea	12.10–22.10	–	–	–	0.41–0.50	0.30–0.37
Festuca pratense	10.92–23.07	20.37–34.09	2.12–4.72	7.19–14.39	–	–

Source UHF (1988); [a] Mhaiskar (2012)
CP crude protein, CF crude fibre

Table 2.7 Erodibility characteristics of soils under different land uses under mid-hill conditions

Location (Land use)	Dispersion ratio	Erosion ratio	WSA (%) (>0.25 mm dia)	MWD (mm)
Nauni (C)	18.92	17.78	72.11	2.70
Nauni (O)	14.46	13.42	89.17	3.86
Lavighat (C)	20.42	21.14	68.36	1.73
Mukhari (C)	21.82	20.80	66.24	1.25
Randon Ghonron (C)	18.50	19.92	79.32	2.80
Majhat (F)	12.93	14.38	93.27	5.49
Kandhaghat (O)	13.25	15.50	92.89	4.26
Ranno (F)	11.64	13.24	95.32	5.22

C Cultivation, *F* Forest, *O* Orchard, *WSA* Water stable aggregates; *MWD* Mean Weight Diameter
Source Kumar et al. (2002)

Table 2.8 Effect of land use and slope on soil loss (t ha^{-1}) under mid-hill conditions

Percent slope → Land use category ↓	5–10	10–15	15–35	>35	Total	Area (ha)	Weighted soil loss (t ha^{-1} yr^{-1})
Dense forests	0.01	5.43	2.31	1.49	9.24	2,674.15	3.46
Mixed forests	0.05	1.81	3.85	6.38	12.09	1,366.29	8.85
Moderately dense forests	0.02	2.92	21.25	9.01	33.20	3,461.14	9.59
Degraded forests	0.00	5.44	7.66	6.88	19.98	1,124.86	17.76
Fruit-based cropping system	0.07	8.86	13.00	26.66	48.59	2,659.33	18.27
Intensive cultivation (sole)	1.73	59.77	38.12	54.47	154.09	2,617.33	58.87
Barren lands	0.00	6.14	11.16	12.76	30.06	349.34	86.05
Soil loss (1000 tonnes)	1.88	98.24	100.80	137.39	338.31		
Area (ha)	177.40	5,737.00	5,250.40	535.15			

Source Sharma et al. (2002)

Identification of Agroforestry Systems Under Different Land Holding Categories

During diagnostic surveys, different indigenous agroforestry systems were identified and their prevailing intensity on different land holdings was also surveyed and is presented in Table 2.10.

The marginal and small farmers usually maintain and develop all types of agroforestry systems on their agriculture field bunds and also in the homesteads/kitchen gardens. They grow trees and vegetables to meet their own requirement as well as retain fodder trees to feed the cattle during lean periods in all the agro-climatic zones. They also keep a unit of their land under fruit trees, vegetable crops, and grasses (cut and

Table 2.9 Effect of block plantation of agroforestry species on physico-chemical properties of the soil

Name of the species	OC (%)	pH	EC_2 (dSm^{-1})	Avail.N (kg ha^{-1})	Avail.P (kg ha^{-1})	Avail. K (kg ha^{-1})	Ex. Ca (kg ha^{-1})
Albizia stipulata	2.74	7.1	0.33	458	39	437	5337
Acer oblongum	2.13	7.1	0.36	415	30	422	5285
Bauhinia retusa	2.27	7.1	0.34	459	40	477	5477
B. variegata	2.55	7.2	0.34	386	29	370	5275
Bombax ceiba	2.29	7.0	0.35	317	38	438	5127
Celtis australis	2.01	7.1	0.35	307	33	448	5369
Dalbergia sissoo	2.51	7.1	0.34	459	32	409	5880
Grevillea robusta	2.27	7.0	0.30	329	31	337	5516
Grewia optiva	2.30	7.1	0.34	273	41	459	5409
Melia composita	2.21	7.2	0.36	250	40	357	5191
Robinia pseudoacacia	2.46	7.2	0.34	474	39	420	5673
Sapindus mukorossi	2.34	7.0	0.33	304	30	437	5275
Terminalia arjuna	2.38	7.0	0.35	275	28	388	4175
Toona ciliata	1.90	6.9	0.35	361	30	336	4873
Prunus armeniaca	2.06	7.1	0.36	329	30	443	5093
Punica granatum	2.38	7.1	0.33	292	29	392	47.60
Paulownia fortunii	2.67	7.0	0.29	279	30	423	5182
Quercus leucotrichophora	1.93	7.0	0.36	319	27	349	5384
Ulmus villosa	2.75	7.0	0.35	321	29	431	4984
Control	1.85	7.1	0.36	251	24	315	3802

Source UHF (2010)

carry) to feed the livestock. The pasture land for grazing is generally state-owned common *Panchayat* or a community land or the state forest department owned land. Every farmer keeps a small unit of land for hay making (*ghasnies*) to feed their cattle in the winter season.

Improved and Managed Agroforestry Systems

There are many possibilities of interventions into the traditional agroforestry systems due to accumulated knowledge through research and have other technological opportunities. Based on research and experiences of farmers the following agroforestry systems in Western Himalayan regions are suggested for adaptations in different regions:

Subtropical Low Hill Zone

The dominant, successful, and remunerative agroforestry systems in low hill subtropical zone include Kinnow (*Citrus*) or mango (*Mangifera indica*)- based cropping systems; poplar (*Populus deltoides*) and *Eucalyptus* based agri-silvicultural systems; multipurpose (mainly fodder) trees in the *ghasnies* (grass lands); and trees on field bunds and along slopping lands which also support growing of fodder grasses, etc., for generating additional farm income along with meeting their own domestic requirements.

Sometime block plantations of poplar and eucalyptus are also carried out by the big or absentee farmers to supply commercial raw material to the wood-based industries or to the local saw mills/furniture manufacturers to enhance their income. These days Poplar based cropping systems are quite frequently found

Table 2.10 Occurrence of agroforestry systems in Himachal Pradesh

Agroforestry systems	Famers categories					
	Uplands			Low land		
	Marginal (<1 ha)	Small (1–2 ha)	Medium (2–5 ha)	Marginal (<1 ha)	Small (1–2 ha)	Medium (2–5 ha)
i. Low hill subtropical region (<1000 m amsl)						
Agri-silviculture	–[c]	–[c]	–[a]	–[c]	–[c]	–[a]
Agri-silvi-horticulture	–[b]	–[b]	–[b]	–[b]	–[b]	–[b]
Pastoral- silviculture	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
Pastoral -silvi-horticulture	–[b]	–[a]	–[a]	–[b]	–[a]	–[a]
Pastoral-horticulture	–[b]	–[a]	–[a]	–[a]	–[a]	–[a]

Agroforestry systems	Famers categories			
	Marginal (<1 ha)	Small (1–2 ha)	Medium (2–5 ha)	Large (>5 ha)
ii. Mid-hill moist temperate region at Nauni (1275 m amsl) in Solan district				
Agri-silviculture	–[b]	–[b]	–[a]	–[a]
Agri-silvi-horticulture	–[b]	–[a]	–[a]	–[a]
Silvopastoral	–[c]	–[b]	–[b]	–[a]
Silvo-horti-pastoral	–[b]	–[b]	–[a]	–[b]
Horti-pastoral	–[b]	–[b]	–[b]	–[c]

Agroforestry systems	Famers categories					
	Uplands			Low land		
	Marginal (<1 ha)	Small (1–2 ha)	Medium (2–5 ha)	Marginal (<1 ha)	Small (1–2 ha)	Medium (2–5 ha)
iii. Moist temperate high hills (2000–3000 m amsl)						
Agri-silviculture	–[c]	–[b]	–[b]	–[b]	–[b]	–[b]
Agri-silvi-horticulture	–[b]	–[b]	–[b]	–[b]	–[b]	–[b]
Silvopastoral	–[b]	–[b]	–[c]	–[b]	–[b]	–[b]
Horti-pastoral	–[c]	–[c]	–[c]	–[b]	–[b]	–[b]
Horti-silvopastoral	–[b]	–[b]	–[b]	–[a]	–[a]	–[a]

Agroforestry systems	Famers categories					
	Uplands			Low land		
	Marginal (<1 ha)	Small (2–5 ha)	Medium (>5 ha)	Marginal (<1 ha)	Small (2–5 ha)	Medium (>5 ha)
iv. High hill dry temperate (devoid vegetation) and cold desert (>3000 m amsl)						
Agri-silviculture	–[b]	–[b]	–[b]	–[c]	–[c]	–[c]
Agri-horticulture	–[c]	–[c]	–[c]	–[b]	–[b]	–[b]
Agri-silvo-horticulture	–[c]	–[c]	–[c]	–[b]	–[b]	–[b]
Silvopastoral	–[b]	–[b]	–[c]	–[b]	–[b]	–[b]
Silvo-horti-pastoral	–[a]	–[b]	–[b]	–[a]	–[a]	–[b]

[a] Absent/Partial; [b] Supportive; [c] Major
Source Modified from Verma et al. (2007)

Table 2.11 Economics of agri-horticultural system (Kinnow + wheat and Kinnow + mustard)

Crops	Cost (INR ha^{-1})						Total cost (INR ha^{-1})	Returns (INR ha^{-1})	
	Input			Labor				Gross	Net
	Seed	Ferti	Total	Bullock	Human	Total			
Wheat	1,500	5,165	6,665	6,400	6,200	12,600	19,265	29,868	10,603
Mustard	240	3,234	3,474	2,200	3,500	5,700	9,174	24,030	14,845
Kinnow (275 plants/ ha)	….	…..	10,196	…..	12,287	12,287	36,335[a]	83,505	47,170
Wheat+ Kinnow	1,205	4,151	15,523	5,143	4,983	22,412	51,787	1,04,857	53,070
Mustard + Kinnow	193	2,599	12,988	1,768	2,813	16,868	43,708	1,00,115	56,408

[a] INR 13,852 for orchard establishment cost is also included; Av. Yield 45 kg per plant of Kinnow (12 year age) has been considered in the analysis. (US $ 1 = INR 43.41, Dec, 2008)
Source Sharma et al. (2008)

Fig. 2.5 Poplar (*Populus deltoides*) with turmeric (*Curcuma domestica*) as inter-crop)

particularly with commercial crops (Fig. 2.5) like turmeric (*Curcuma domestica*) and ginger (*Zingiber officinale*).

Success Story Related to Fruit Trees-Based Cropping System in the Region

In the subtropical low hill zone valley the farmers of Nurpur (Kangra), Nadaun, Hamirpur, and Una districts of Himachal Pradesh are getting net return of INR 10,603 and 14,845 per hectare from wheat (*Triticum aestivum*) and mustard (*Brassica juncea*) crops, respectively when these are grown on slopes along with Kinnow (*Citrus* sp) fruit trees. The net return from Kinnow (12 years old plantation) as sole crop was INR 47,170 per hectare but when wheat and mustard were integrated with Kinnow, the net return increased to INR 56,048 (Table 2.11). The analysis revealed that cultivation of mustard is more profitable as compared to wheat with Kinnow. However, the net profits in both the cases were higher as compared to the sole Kinnow. Economics of agri-horticultural systems revealed that both gross as well as the net returns increased on per hectare basis. Agroforestry models are thus important to enhance the land use efficiency as well as productivity.

Forest and Fruit Trees-Based Cropping System

A cropping system was developed which is consisted of Kinnow-mandarin (*Citrus nobilis* × *C. deliciosa*) 400 plants per hectare, subabul

(*Leucaena leucocephala*) in quincunx method at varying plant density (0, 100, 166, and 277 plants ha^{-1}) such as woody perennials and agricultural crops viz., wheat (*Triticum aestivum*) and mash (*Lens culinaris*) grown under irrigated conditions. Various yield parameters are shown in Table 2.12.

The maximum number of fruits (174 thousands ha^{-1}) which is the only economical part of the system for sale, fodder yield (2504 kg ha^{-1}), and fuel-wood yield (1593 kg ha^{-1}) were obtained when Kinnow was spaced at 5 m x 5 m and *Leucaena* trees were planted at a distance of 10 m × 5 m in between the rows of Kinnow. It is evident from the table that there is decrease in agriculture crop yield in the system when density of *Leucaena* trees is increased; on the other hand there is a significant increase of Kinnow fruits by incorporating *Leucaena* plants. The *Leucaena* plants fix the atmospheric nitrogen and improved the soil fertility which is available to the Kinnow trees and also provide additional benefits in terms of fuel wood and fodder for livelihood subsistence of the farmers. It is, therefore, very important that horticultural crops planted at standard distance should be incorporated with leguminous fodder trees for enhancing the income as well as livelihood subsistence in the region.

Agri-silvicultural System

In subtropical low hills, i.e., Ponta valley of Himachal Pradesh, different varieties of sugar cane (*Saccharum officinarum*), i.e., Co 88, Co 767, Coj 64, and Co 7717 were cultivated under different clones of poplar (*Populus deltoides*), i.e., PD 3294, PD G3, PD G48, and PD 1/56; which were planted at 5 × 5 m spacing. The bole girth of the poplar trees varies significantly and was maximum in clone PD G48 and maximum average cane yield was recorded to be 117 t ha^{-1} in clone Co 7717 followed by 116.5 t ha^{-1} in Coj 64 under poplar plantation as compare to Co 767 (112 t ha^{-1}) and Co 88 (107 t ha^{-1}). Hence, Co 7717 and Coj 64 of sugarcane were found suitable for successful growing under poplar based agroforestry system (Table 2.13).

Mid-hill Subhumid Zone

Intercropping of Aromatic and Medicinal Plants Under High Density Peach Plantation

The yield of fruits increased when aromatic and medicinal plants namely Tulsi (*Ocimum sanctum*), Ashwgandha (*Withania somifera*), and Kalmeghh (*Andrographis paniculata*) were grown between the rows of high density (4.5 m row-to-row and 2 m plant-to-plant) of 5-year-old peach (*Prunus persica*) plantations in the mid-hill Himalayas. There was a significant increase in yield of peach (4.5 × 2.5 m) by 7.77, 11.8, and 9.02 % with Tulsi, Ashwagandha, and Kalmegh, respectively over sole peach (Table 2.14; Fig. 2.6). It was also observed that under peach plantation, there was a significant increase in biomass of all these medicinal plants showing that partial shade is helping the growth of these plants.

The growing of aromatic and medicinal plants under fruit trees is highly profitable. Thakur et al. (2010) and Verma et al. (2010) also recommended growing of *Digitalis lanata, Matricarea chamomilla, Salvia sclaria,* and *Ocimum basilicum* with poplar (*Populus deltoides*) as shade tolerant intercrops and were proved to be good option for farm diversification. Verma and Thakur (2010) recommended the cultivation of *Withania somnifera* (Ashwagandha) with peach, and also with fruit tree *Morus alba* and grass *Setaria* for high productivity and profitability.

Carbon Sequestration in Peach, Aromatic, and Medicinal Plants Based Agroforestry Systems

The rate of carbon sequestration in the aromatic and medicinal plants was comparatively higher than the sole crops, i.e., 1.21, 0.87, and 1.14 t ha^{-1} yr^{-1} in Tulsi, Ashwagandha, and Kalmeghh under high density peach plantation in comparison to 1.00, 0.60, and 0.89 t ha^{-1}year^{-1}in the open sole crops, respectively. The rate of change in 1 year was highest in sole peach plantation being a perennial crop, and due to increase in growth with the age, i.e., 0.20 t ha^{-1} year^{-1}. In Ashwagandha under peach, the rate of change in

Table 2.12 Fruit, fodder, fuelwood, and grain yield under forest and fruit tree-based system

AF system Δ	*Number of fruits (000 ha^{-1})	Leucaena dry fodder yield (kg ha^{-1})	Fuelwood yield (kg ha^{-1})	Wheat yield (kg ha^{-1})	Mash yield (kg ha^{-1})
K (400) + A	143	–	–	890	450
K (400) + L (100) + A	159	15	898	855	426
	(+11.3)			(−3.9)	(−5.6)
K (400) + L (166) + A	174	25	1593	795	3.6
	(+21.8)			(−10.7)	(−19.3)
K (400) + L (277) + A	132	38	2339	695	321
	(−7.6)			(−21.9)	(−28.7)

Parenthesis represents the percentage increase (+) or decrease (−); *Number of Kinnow per kg = 8–10
K Kinnow-mandarin, *L Leucaena* and *A* Agriculture crops-wheat in *rabi* and mash in *kharif*
Δ Figure in brackets shows number of trees; *Source* Chauhan et al. (1997)

Table 2.13 Growth parameters of trees and cane yield (tons ha^{-1}) of sugarcane varieties grown under different poplar clones

Poplar clone	Growth		Sugarcane yield (tons ha^{-1})				
	Height (m)	DBH (cm)	Co 88	Co 767	Co j64	Co 7717	Mean
PD 3294	13.13	13.58	106.60	112.40	115.56	118.77	113.33
PD G3	14.27	14.34	105.97	111.90	116.90	116.33	112.77
PD G48	14.94	14.60	102.50	111.20	115.66	115.66	111.25
PD 1/56	14.45	14.44	111.50	112.50	117.97	116.93	114.72
Mean			106.64	112.00	116.52	116.92	

Source Chauhan and Dhiman (2003) *DBH* diameter at breast height

Table 2.14 Yield of peach fruits and biomass production of three medicinal plants when grown in different agroforestry systems in mid-hill Himalayas

Agroforestry components		Fruit yield (t ha^{-1})	Above ground biomass of medicinal plants (t ha^{-1})	Below ground biomass of medicinal plants (t ha^{-1})
(i)	Peach (sole) at 4.5 m x 2.5 m	3.99	–	–
(ii)	Tulsi with peach	4.30	2.30	0.37
		(7.77)	(21.06)	(12.12)
(iii)	Ashwagandha with peach	4.46	1.01	0.79
		(11.78)	(46.38)	(21.54)
(iv)	Kalmeghh with peach	4.35	2.31	0.17
		(9.02)	(26.23)	(13.13)
(v)	Tulsi (sole)	–	1.90	0.33
(vi)	Ashwagandha (Sole)	–	0.69	0.65
(vii)	Kalmegh (sole)	–	1.83	0.15

Parenthesis represents the percentage increase
Source Tripathi (2012)

consecutive year was maximum, i.e., 0.12 t $ha^{-1}yr^{-1}$ and minimum was −0.15 t ha^{-1} yr^{-1} in Tulsi, i.e., productivity reduced because it is a light demanding species. Similarly, rate of carbon emission and mitigation t $ha^{-1}year^{-1}$ in aromatic and medicinal plants was higher under peach than

Fig. 2.6 Tulsi (*Ocimum sanctum)* cultivated as intercrop with peach (*Prunus persica*)

in the open due to more biomass production (Table 2.15). Therefore, agroforestry with aromatic and medicinal plants in the mid-hill sub-humid zone of the Himalayan region is a viable option for climate change for CO_2 mitigation.

Biomass Production in Improved Silvopastoral System

A silvopastoral system was established on undulating farm land having slope more than 50 % to meet the fodder requirement of the cattle as one of the livelihood subsistence. The plantation of four promising fodder trees, i.e., *Celtis australis, Morus alba, Grewia optiva*, and *Leucaena leucocephala* was done in *gradonies* (continuous contour trenches) in alleys, i.e., at 1 m (plant-to-plant) and 4 m (row-to-row) apart. In between the rows, the grass *Setaria anceps* var. Kanachangula was planted intensively to have a complete land coverage. The single row fodder trees were pollarded at 0.5 m height, in other single row fodder tree pollarded at 1.5 m height and double row of fodder trees (0.5 m apart) pollarded as single row at 0.5 m and second row at 1.5 m height. The data for leaf fodder, branches as fuel wood, and grass planted underneath were recorded consecutively for 2 years after 12 years of plantation. It was observed that leaf fodder production was comparatively higher in *Morus alba* in all pollarding heights and varied from 1680 kg ha^{-1} at 1.5 m pollarding height to 2726 kg ha^{-1} pollarding at 0.5 m and 1.5 m height together. The mean leaf fodder production was 1897 kg ha^{-1} followed by 1767 kg ha^{-1} in *Leucaena leucocephala,* 699 kg ha^{-1} in *Grewia optiva*, and 263 kg ha^{-1} in *Celtis australis*. The overall productivity including grass grown under the trees between the rows was maximum in the *Morus alba* based agroforestry systems, i.e., 15.42 t ha^{-1} followed by 12.4 t ha^{-1} in *Leucaena leucocephala,* 9.91 t ha^{-1} in *Grewia optiva,* and minimum (9.5 t ha^{-1}) in *Celtis australis*. The available nitrogen increased from 280 to 307 kg ha^{-1}, available P from 1.7 to 20.7 kg ha^{-1}, available K from 327 to 345 kg ha^{-1}, available sulfur from 23 to 29 mg kg^{-1}, exchangeable Ca contents from 1301 to 1943 mg kg^{-1}, and exchangeable Mg from 261 to 312 mg kg^{-1}, respectively (UHF 2006).

Table 2.15 Carbon sequestration; emission and mitigation (t ha^{-1}yr^{-1}) in peach-based agroforestry system involving medicinal and aromatic plants

Agroforestry components	Rate of carbon sequestration		Rate of carbon emission		Rate of carbon mitigation	
Peach (Sole) 1111 plants ha^{-1} at 4.5 m x 2.5 m spacing	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr
	1.71	1.91	0.39	0.43	1.32	1.48
Ocimum sanctum (sole)	1.08	1.92	0.81	0.66	0.27	0.26
Withania somnifera (sole)	0.61	0.60	0.34	0.36	0.26	0.25
Andrographis peniculata (sole)	0.81	0.97	0.54	0.68	0.27	0.28
Peach + *O. sanctum*	1.28	1.13	0.95	0.82	0.33	0.30
Peach + *W. somnifera*	0.75	0.87	0.46	0.58	0.28	0.29
Peach + *A. peniculata*	1.09	1.14	0.78	0.81	0.31	0.32
Mean	1.04	1.05	0.73	0.77	0.31	0.30

Source Tripathi (2012)

These *gradonies* not only conserve the moisture but also check the run off during the rainy season. The trenches are generally filled with soil particles (silt and organic matter) due to which the survival and growth of the trees increased. The similar study which was also conducted by Singh et al. (2008) in Shiwalik foot hills on research farm of the Central Soil and Water Conservation Research Training Institute, Dehradun; *Grewia optiva* was planted in the pits (45 × 45 × 45 cm) at 4 × 4 m spacing with a density of 625 trees ha^{-1} and Hybrid Napier grass (*Pennisetum purpureum*) was planted in inter-spaces. After 10 years, it was concluded that *Grewia optiva* trees planted alone or along with Napier hybrid, the biomass of both the components decreased significantly with time after 5 years (lopping and pollarding) of *Grewia optiva* and biomass from cuttings of Hybrid Napier varied from 256 to 2181 kg ha^{-1}.

In other studies when fodder trees, i.e., *Morus alba, Celtis australis, Grewia optiva,* and *Bauhinia variegata* were lopped at different cutting heights of 0.5, 1.0, 1.5, and 2.0 m; the maximum leaf + branch biomass accumulated in *Morus alba*, i.e., 7.38 t ha^{-1} followed by 2.16, 1.44, and 1.31 t ha^{-1} in *Grewia optiva, Bauhinia variegata*, and *Celtis australis*, respectively in 4 years old plantation at 2 m cutting height (Chand et al. 2008). There was significant variation in leaf N, P, K, Ca, and Mg concentrations irrespective of cutting heights. In both the cases the plantation was done in continuous contour trenches, i.e., *gradonies* on the hill slopes. Hence, it is recommended that in the sloppy areas of the region, the plantations should be carried out in the *gradonies* or continuous contour trenches to enhance the survival, growth, and biomass productivity.

Bamboo-Based Agroforestry System

Economic analysis of the bamboo-based agroforestry systems (Table 2.16) reveals that the returns from agricultural crops are quite higher than from the sole bamboo-based systems.

The returns from the bamboo species are in the order of *Dendrocalamus asper*, *D. hamiltonii*, and *Bambusa balcoa,* respectively. *Dendrocalamus asper* culms are edible and are used for making pickles, candy vegetables, etc., by the food processing industries and are sold at higher prices than other bamboo species of the region. Similarly, the *D. asper* clumps are managed at lower heights as young culms are harvested regularly for pickle and candy making thus shade loving agriculture crops viz. turmeric (*Curcuma domestica*), soybean (*Glycine max*), ginger (*Zingiber officinale*), colocacia (*Colocasia esculenta*), and white yam (*Dioscorea alata*) are grown successfully under its canopy (Fig. 2.7). The other bamboo species are not viable options for the rainfed agroforestry systems till the market price of mature bamboo are established. There is an urgent need to establish bamboo-based cottage industries, low cost poly houses, and low cost activated charcoal or pulp and paper industries. The consumption can be made compulsory by incorporating the bamboo pulp with other hard wood pulp for the construction of tents, floors, and houses.

High Hill Temperate Wet Zone

Economics of Apple-Based Cropping System

One study was conducted on apple (*Malus pumila*) based agroforestry in Kullu district of Himachal Pradesh. It revealed that the average cost of cultivation of apple was INR 3,88,850 $ha^{-1}$and the average net benefit from the orchard by selling fruit was INR 10,45,523 ha^{-1} (Table 2.17). The integration of high value crops such as tomato (*Solanum lycopersicon*), pea (*Pisum sativum*), French bean (*Phaseolus vulgaris*), and mustard (*Brassica juncea*) in the system (Fig. 2.8) not only offered diversification in different growing seasons but also generated surplus income without affecting the fruit yield of the orchard (Table 2.18). However, there was significant loss (INR 57,494 ha^{-1}) in the old traditional system when wheat was integrated as a cereal crop under apple. The average data of two consecutive years revealed that growing of pea (*Pisum sativum*) as a substitute crop for wheat in winter season benefitted the farmers to the extent of

Table 2.16 Economic analysis of bamboo-based agroforestry systems

Sr. No.	Bamboo species	Agricultural crops combination	Return from agricultural crop (INR ha^{-1})	Returns from bamboo (INR ha^{-1})	Total (INR ha^{-1})
1.	*Dendrocalamus hamiltonii*	Tulsi	1,40,050	5,817	1,45,867
		Ginger	74,520	5,817	80,377
		Soybean	26,900	5,817	32,717
		Turmeric	81,000	5,817	86,817
		Aloe vera	1,92,030	5,817	1,97,847
2.	*D. asper*	Tulsi	2,62,800	14,293	2,77,093
		Ginger	3,90,400	14,293	4,04,693
		Soybean	30,650	14,293	44,943
		Turmeric	86,000	14,293	1,00,293
		Aloe vera	90,000	14,293	1,04,293
3.	*Bambusa balcoa*	Tulsi	2,53,300	3,253	2,56,553
		Ginger	89,680	3,253	92,933
		Soybean	14,400	3,253	17,653
		Turmeric	76,000	3,253	79,253
		Aloe vera	19,660	3,253	22,913
4.	Open plot	Tulsi	2,59,550	–	2,59,550
		Ginger	1,57,600	–	1,57,600
		Soybean	19,400	–	19,400
		Turmeric	71,000	–	71,000
		Aloe vera	1,98,620	–	1,98,620

Source UHF (2012) US $ 1 = Rs. 52.40

Fig. 2.7 Bamboo-based agroforestry system: Tulsi, ginger, soybean, turmeric, and aloe vera as inter-crop

INR 2,84,676 ha^{-1} and INR 5,31,966 ha^{-1} in the *kharif* season from the cultivation of tomato.

Hence, it is recommended that high value vegetable crops, such as beans, peas, tomato, cauliflower, cabbage, *broccoli* as off-season vegetable can be integrated in the temperate orchards to increase the farm income.

Agri-silviculture in Kashmir Valley

Experiments were conducted on hill slopes by planting *Ulmus wallichiana* as a tree crop in alleys across the slope at a distance of 1, 1.5, and 2 m row-to-row and were pruned every year at 3 m height for fodder and fuel wood. In between the rows peas and beans were planted in *rabi* and *kharif* seasons, respectively. After 10 years, it was found that there was an increase in average cumulative yield of both *rabi* and *kharif* crops when compared with the average cumulative yield of crops obtained in the control without any plantation. Increase in yield of pea and beans was to the tune of 314.34 and 454.67 kg ha^{-1} over the control, i.e., outside alleys, respectively. (Table 2.19).

Besides the maximum yield of 950 kg ha^{-1} of peas and 1165 kg ha^{-1} of beans were recorded in an alley width of 2 m. In addition to yield of peas and beans, yield from *Ulmus wallichiana* trees in the form of fodder and fuel wood yielded

Table 2.17 Economics of apple-based cropping system in northwestern regions

Years	No. of trees ha^{-1}	Average fruit yield (kg $tree^{-1}$)	Fruit yield (t ha^{-1})	Selling price (Rs kg^{-1})	Gross return (INR ha^{-1})	Total expenses (INR ha^{-1})	Net benefit (INR ha^{-1})	Benefit: cost ratio
1st	278	194.06	54.0	22	11,86,870	3,88,851	7,98,019	3.05
2nd	278	189.06	52.6	32	16,81,877	3,88,851	12,93,026	4.32
Average					14,34,374	3,88,851	10,45,523	3.69

Source Anjulo (2009) 1 US $ = 46.80 INR, Dec., 2009

Table 2.18 Average yield, expenses, and return from annual crops in apple-based cropping system

Crop	Average yield (t ha^{-1})	Selling price (INR kg^{-1})	Gross return (INR ha^{-1})	Total expenses (Rs ha^{-1})	Net benefit (Rs ha^{-1})	Benefit cost ratio
Wheat	2.1 (4.0)	10	21,000	97,074	−26,074	0.22
			(39,580)		(−57,494)	(0.41)
Pea	8.8	50	4,40,000	15,5,324	+2,84,676	2.83
	(11.8)		(5,89,400)		(4,34,076)	(3.79)
Tomato	73.6	10	7,36,000	2,04,034	+5,31,966	3.61
	(6.2)		(6,24,000)		(4,19,966)	(3.06)
French beans	4.5	50	2,25,000	99,940	+1,25,060	2.25
	(5.2)		(25,75,00)		(1,57,560)	(2.58)

1 US $ = 46.80, INR Value in parenthesis represent the control, i.e., sole crops with orchards
Source Anjulo (2009)

Fig. 2.8 Cultivation of apple (*Malus pumila*) with mustard (*Brassica juncea*) in Himachal Pradesh

additional benefits. Maximum fodder yield (8.43 kg $tree^{-1}yr^{-1}$) was obtained in closely spaced alleys and maximum fuel wood of 14.22 t ha^{-1} was obtained where alley width was maintained at 1.5 m (Table 2.20).

Thus, agri-silviculture model so devised can help in stabilizing the degraded environment and at the same time helps the farmer for increasing yield and security of food, fuel wood, and fodder.

Table 2.19 Average production of agricultural crops over a period of 10 years

Crop	Yield outside alley (kg ha^{-1})	Yield within alley (kg ha^{-1})	Increase in yield over control (kg ha^{-1})	Percentage increase over control
Rabi (Peas)	554	868.34	314.34	56.77
Kharif (Beans)	566	1014.67	454.67	81.19

Table 2.20 Average yield of crop, fodder, and fuel wood under different alleys

Alley width (Row-to-row)	Crop yield (kg ha^{-1})		Fodder yield (kg $tree^{-1}yr^{-1}$)	Fuel wood (t ha^{-1})
	Rabi	Kharif		
2 m	949.92	1164.67	5.31	10.30
1.5 m	845.84	1080.76	5.40	14.42
1 m	819.26	798.60	8.43	13.09

Source Mughal et al. (2003)

Fruit Trees-Based Pastoral Model in Kashmir Valley

About 2.5 lakh ha area is under apple (*Malus pumila*), almond (*Prunus amygdalus*), cherry (*P. avium*), and other stone fruits in the Kashmir valley. Due to increase in the cattle population, there is an acute shortage of fodder and accordingly growing or cultivating of grasses in orchards is essential to feed them. A scientific fruit trees—based pastoral system was developed in the valley and accordingly evaluated for temperate legumes and grasses. The four grasses, i.e., *Festuca pratense* (fescue), *Dactylis glomerata* (orchard grass), *Trifolium repense* (white clover), and *Trifolium pratense* (clover) were compared with natural undergrowth under fully grown almond orchard. The natural undergrowth of herbaceous vegetation in the orchard was identified as: *Plantago major, Plantago lanceolata, Poa bulbosa* (Poa grass), *Trifolium repense,* and *Indigofera articulata*. A 3 years data showed that all introduced grasses and legumes have higher yield than natural undergrowth grasses (Table 2.21).

The soil analysis revealed that there was negligible change in soil pH and EC; whereas organic matter (OM), and available N increased by continuous cropping and depleted the available P_2O_5 and K_2O by 6.6 and 10.1 %, respectively. Grasses as under storey crops are usually better than crops because the forage grows taller under shade and therefore, associate with trees without loss of yield and there is no root competition. The grasses are also good soil binder.

High Hills Dry Temperate Zone

Aromatic and Medicinal Plants

Cold desert areas of J & K and Himachal are suitable to grow aromatic and medicinal plants along with woody perennials, i.e., salix, poplar, seabuckthorn, etc., which are maintained by the farmers to meet their fuel and fodder requirement. *Salvia sclarea* (Clary sage), an aromatic herb, which produces linalool and linalyl acetate as a main constituent of aromatic oil used in perfumery and generally imported from the France by Indian industries. *Salvia* is a summer crop planted in the first week of May and harvested in the month of September and October for oil extraction. The experiments were carried out at Kashmir valley and Ladakh cold desert area in the open as well as in the polyhouse. The essential oil percentage was found to be 0.2–0.3 % in the open field and 0.5–0.7 % in the polyhouse plantations. Qualitative estimation have shown that the oil from open field conditions contained 26.62 % Linalool and 27.66 % linalyl acetate, whereas under polyhouse conditions it showed improvement and rose to 28.38

Table 2.21 Green forage yield (tons ha^{-1}) of pasture and legumes

Name of grass		Years			Average Yield (t ha^{-1})	% increase over natural vegetation
		1990	1991	1992		
(i)	Natural grass/ vegetation	12.89	17.54	13.50	14.64	–
(ii)	*Dactylis glomerata*	20.95	22.96	22.19	22.03	56
(iii)	*Festuca pratense*	20.47	42.48	21.25	28.07	91
(iv)	*Trifolium repense*	22.80	34.56	17.51	24.96	70
(v)	*Trifolium pratense*	23.00	31.92	18.33	24.58	62
	CD at 5 %	7.89	9.56	4.46	–	–

Source Makaya and Gangoo (1995)

Table 2.22 *Salvia sclarea* (Clarysage) oil: comparison of Linalool and Linalyl acetate in oil from Kashmir and Ladakh

Source		Linalool %	Linalyl acetate (%)
(i)	Kashmir	18.32	32.70
(ii)	Ladakh		
(a)	Open field	26.62	37.66
(b)	Polyhouse	28.38	50.65

and 50.65 %, respectively (Table 2.22). The quantity of essential oil, and linalool and linalyl acetate extracted in polyhouse condition was higher than in open field (Table 2.23).

This indicates that besides vegetables there are good scope of cultivating medicinal and aromatic plants in cold desert area along with indigenous woody perennials like *Hippophae* and *Salix* which are maintained for fuel, fodder, and timber, etc. Further, there is tremendous scope of developing livestock based silvopastoral systems particularly involving small ruminants.

In the Lahaul valley farmers maintain tree species on the boundaries of the cultivated fields in sparse situation or with low density. *Hippophae rhamnoides, Juglans regia, Populus nigra, Prunus armeniaca, Prunus communis,* and *Salix* sp. were noted among the important agroforestry species in the cold dessert of the

Table 2.23 Quality evaluation of oil *Salvia sclarea* from open field and polyhouse conditions in Ladakh

Habitat		Herbage (t ha^{-1})	Different yield parameters			
			Essential oil yield			
			(kg ha^{-1})	Oil (%)	Linalool (%)	Linalyl acetate (%)
(i)	Polyhouse (Stakna, Ladakh site)	12.50	8.70	0.50–0.70	28.38	50.65
(ii)	Open field (Thiksey, Ladakh site)	10.00	3.00	0.20-0.30	26.62	37.66
Down stream products						
Products			Uses			
(i)	Clarysage concrete		High value perfumery product			
(ii)	Clarysage absolute		Excellent modifier yield 3–4 times higher than essential oil			
(iii)	Selareol		Used as best fixative, high value in odorous chemical			

Source Kaul et al. (2006)

Table 2.24 Fuel wood and fodder production (kg) from indigenous agroforestry system of Lahaul valley of Himachal Pradesh

Production	Study area					
	Khoksar[1]		Jahlma[2]		Hinsa[2]	
	kg per tree	kg per ha	kg per tree	kg per ha	kg per tree	kg per ha
Hippophae sp.[3] fuel wood	–	–	31	59	25	10
Salix sp. fuel wood	110	319	213	260	240	144
Fodder	15	44	20.5	25	21.5	13

[1] Harvested after 4 years, [2] Harvested after 3 years, and [3] Harvested after 5 years
Source Kuniyal et al. (2001)

Lahaul valley. *Salix* species (willow) and sea-buck-thorn are the major woody perennial components in the traditional agroforestry system along with annual/perennial medicinal and aromatic plants or arable crops like barley. The woody perennials are maintained on bunds of farmers' fields for fuel, fodder, food, and timber purposes. The fuel wood and fodder production of both the species in different areas of Lahaul valley of Himachal Pradesh have been recorded (Table 2.24).

The fuel wood production of *Salix* varies from 144 to 319 kg ha^{-1} and fodder production varies from 13 to 44 kg ha^{-1}. However, in case of *Hippophae*, the fuel wood production from the two sides varies from 10 to 59 kg ha^{-1} (Table 2.24). The study sites are in the cold arid region having altitude range from 2400 to 6400 m amsl. The soils are sandy and erodible (Kuniyal et al. 2001).

Conclusions

Agroforestry in Northwestern Himalayan regions is a composite, diversified, and sustainable land use system. It provides unique opportunity for integration of different components of the farming systems to optimize the ecosystem functioning and better management of land, water, and biological resources. The traditional agroforestry systems and practices consist of growing trees deliberately with various crops and livestock for multiple benefits, viz., fuelwood, fiber, food, fruits, etc., and are time tested and well adopted in different situations. These systems developed over the years have been found suitable for conservation of natural resources, viz., soil, water, and vegetation. During past couple of decades enough research inputs have been added but still many of these systems need to be further improved with suitable technological interventions considering the local population need, so that the socioeconomic status of the farming communities is uplifted. Fruit trees-based cropping systems having medicinal and aromatic plant species as one of the components have been proved quite remunerative and sustainable systems. As live stocks are very important for these regions, hence improvement in pastures through introduction of high yielding grasses and leguminous forages along with fruit trees also need special attention. In recent times due to rise in average temperature due to climate change the apple belt has shifted toward higher altitudes increasing the total area under apple. This phenomenon needs more research inputs in the region.

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