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Alternate land use and agroforestry systems for resource conservation and enhanced productivity in the hills

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ABSTRACT

Sustainable development in the Himalayas' is linked with the development of environment, capacity building of the local people, marketing forces, socio-political situation and the global trade and other related aspects. The challenge before us is to identify meaningful strategies and workable action plans aimed at bringing about the necessary changes in the agricultural production patterns and lifestyle of the people keeping in view the social and developmental priorities. The Indian Himalayas (IH) covers 16.4 per cent of the total geographical area of the country. Ecosystem diversity, fragility, marginality, poor accessibility, biodiversity and cultural heterogeneity are the major issues of livelihood gathering and resource conservation in the region. Agriculture is the main stay of the people in the region. However, faulty management practices coupled with ever-increasing human and animal population are threatening the very base of livelihood in the region. About two-third of the total geographical area in the Himalayan region is affected by land degradation problems. Farmers with small landholdings rely heavily on the common property resources' (CPRs) of forests and grazing lands to provide fuel and fodder supplies. However, invasion of exotic obnoxious weeds in the CPRs is a matter of concern.

Agroforestry is the best option for the restoration of the degraded environment and meeting day-to-day needs of the people, besides mitigating the climate change effects and providing a great opportunity for the rural development. Agroforestry systems (AFS) as models have been developed and evaluated for the varying agro-climatic situation of the region. Agri-silvipasture, agri-horticulture, silvipastoral, agri-horti- silvi-pastoral, horti-pastoral, agri-silvipastoral, AFS with sericulture, apiculture and fisheries with trees, and other systems have been developed for different altitudinal ranges, slopes and soil depths. These AFS strengthened with subsidiary sources of income provide opportunities for all round development and greater employment. Research finding have demonstrated the potential of integrated management of soil and water resources involving agroforestry interventions through watershed planning and management. The priority is being accorded by the Govt. of India to the holistic and sustainable development of rainfed areas based on the watershed approach. There is a great scope to integrate agroforestry systems for resource conservation and enhanced productivity in hills through convergence of various schemes and programmes, which if effectively integrated could bring about the needed change and will optimize the resources.

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1. Introduction

The Himalayas in India cover ten states fully and four partly in two distinct regions of the western Himalayas and the eastern Himalayas. The western Himalayan ranges extend over Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Shiwaliks of Punjab as well as Haryana up to the western border of Nepal. The eastern Himalayan ranges cover northeastern hill (NEH) states of Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, and parts of Assam and West Bengal. The SWOT analysis (Dhyani and Sharda, 2005) of Indian Himalayas indicates ecosystem diversity, fragility, marginality, poor accessibility, biodiversity and cultural heterogeneity as the major issues of livelihood gathering and resource conservation in the region. Wide range of variation in altitude, latitude and longitude generate vast diversity in microclimate, habitats, soils, vegetation and livestock in the region. The Himalayas have the enormous wealth of natural resources of land, water and vegetation, which are under severe threat due to ever-increasing human and livestock population, leading to their ruthless exploitation. These resources have a bearing on not only the inhabitants of the mountains but also affect the life and prosperity of the people in the down plains.

The Indian Himalayas cover an area of 53.8 million ha, which is 16.4 per cent of the total geographical area of the country. About 15 per cent area is permanently covered with snow and provides perennial flow to the vast Indo-Gangetic plains. This water satisfies multiple needs of hydroelectric power, irrigation, drinking, ground water recharge and environmental flushing of the plains. Out of 21 agro-ecological regions of the country, four regions are covered exclusively and one partly in the Himalayan hill and mountain agro-ecosystem. These five agro-ecological zones represent wide variations in climate from cold arid to warm per humid. Annual rainfall in the region recharge and environmental flushing of the plains. Out of 21 agro-ecological regions of the country, four regions are covered exclusively and one partly in the hill and mountain agro-eco system. These five agro-ecological zones represent wide variations in climate from cold arid to warm per humid. Annual rainfall in the region skeletal, calcarious to brown forest podzolic, brown red and red yellow. These soils are alkaline to acidic in nature. The natural vegetation consists of willows, tropical deciduous, temperate and wet evergreen forests (Samra *et al.*, 1999).

The Indian Himalayan region is sparsely populated, having a population density of 627 per 1000 ha. About 56 per cent of the total workforce is engaged in agriculture, as it is the primary sector of the economy contributing 45 per cent to total regional income of the inhabitants. Per capita availability of cultivated land in the region is only 0.17 ha as compared to 0.15 for the whole country. Net cultivated area is higher in the western Himalayan region (15.8 per cent of total geographical area) than in the NEH region (9.8 per cent). Forest is the major land use in the Himalayas and the agrarian economy of the hills is heavily dependent on forest for energy supply, fodder, water, non-timber products and livestock rearing. This vital sector of hill economy is in degraded condition, despite the massive corrective measures by the Government at strategic, operational and policy level.

Farmer's primary objective is the self-sufficiency in food grain production here. They produce all those crops, which can be grown in a harsh environment to meet their food requirements. Therefore, 76 per cent of the gross cropped area in the region is under foodgrain crops such as cereals (rice, wheat, maize, and millets), pulses (beans, peas, kidney bean, blackgram, horsegram, black soybean, lentil, greengram and bengal gram), oilseeds (rapeseed, mustard, sesamum and linseed), potato and sugarcane. Nearly cereals occupy three-fourth of the total area under foodgrain crops. The two Himalayan regions show distinct crop preferences. In the NEH region, rice is the staple food and wheat is cultivated in small areas in Arunachal Pradesh, Meghalaya, Sikkim and Tripura only. This is in sharp contrast to the western Himalayan region where wheat is the principal crop, followed by rice and maize. The millets are confined to Uttarakhand mainly. The high rainfall bestowed by nature is well capitalized by the farmers in terms of relatively higher cropping intensity (136%) than India as a whole (131%). There is an ample scope to further intensify the cultivation of different crops for achieving self-sufficiency in foodgrain production.

The Himalayan ecosystem has relative advantages for horticulture because of its specific environmental conditions and several micro-situations (Samra *et al.*1999). The mountain region represents sub-tropical to temperate climate and a wide range of fruits (citrus, banana, mango, apple, pineapple, walnut, plum, peach, cherry etc.), vegetables (potato, pea, capsicum, cabbage, cauliflower etc.), spices (ginger, chillies, cardamom, saffron etc.) and flowers (orchids, gladiolus, marigold, chrysanthemum etc.) can be grown in the region. Although these crops are well adapted, their cultivation is rather on a small scale at present.

Biodiversity and Climate Change in hills

The region has rich biodiversity along with traditional and indigenous knowledge. It contains a great wealth of biological diversity in its forests, agroforestry, agriculture and other areas. WCMC's Threatened Plants Unit (TPU) has catalogued the world's centres of plant diversity for conservation action. Among the five locations in India, two are in the Himalayan region one in Eastern and another in Western Himalaya. In India, as per Convention on International Trade in Endangered Species (CITES) which ratified the World Heritage Convention there are five natural sites inscribed as areas of 'outstanding universal value', three of them *viz*. Kaziranga, Manas and Nanda Devi National Park are located in this region.

The rich variety of life in Indian Himalayas is now affected with a changing climate. The pace of the change we are presently experiencing in this region is so rapid that a great number of species cannot adapt fast enough to the new conditions, or move to regions more suited for their survival due to habitat fragmentation. Recently, the Millennium Ecosystem Assessment (MEA) indicated that climate change is likely to become the dominant direct driver of biodiversity loss by the end of the century. Current climate change estimates predict increases in temperatures of 1.4oC to 5.8oC by 2100. This will affect species in several ways such as: changes in distribution; increased extinction rates; changes in reproduction timings; and changes in length of growing seasons for plants. The economic, ecological and social consequences of climatic variability will vary by region, but in hill and mountain ecosystem, it is likely to threaten production of cereal, vegetable and fruit crops, species extinction, and flow of water in river system and current livelihood options for the hill farmers, the most. Already there are evidences to indicate that the Himalayan region is warming at a higher rate than the global average rate (Shrestha *et al.* 1999, Jianchu *et al.* 2007). Some of the changes already being noticed by the scientists in this region (Verma, 2007, Maikhuri *et al.* 2003, Joshi and Joshi, 2011), particularly under agriculture sector are mentioned here, but they are to be thoroughly studied before any conclusion can be drawn.

- ❖ Due to large scale burning of straw and industrial pollution thick black clouds are being formed in the foothills of Himalaya during the winter season (Dec.-Jan.), which has critically changed the habitat of highly light demanding species like *Toona ciliata, Dalbergia sissoo* and *Acacia nilotica*, which makes them susceptible to insect pest and disease attack.
- ❖ Frequency and intensity of snowfall has decreased resultantly large-scale mortality in *Robinia pseudoacacia* in sub temperate and lower part of the wet temperate areas is taking place.
- ❖ Tips of *Cedrus deodara* trees growing in sub temperate forests are showing sign of drying from terminal portion because of non-fulfilment of their chilling requirements.
- ❖ Gap between minimum and maximum temperature in dry temperate zone is increasing. This has led to rapid increase in regeneration of *Juniperus macropoda.*

However, these conditions go against the regeneration and establishment of Neoza Pine (*Pinus gerardiana*), an economic tree species of the region.

Long Term Effects

- ❖ The population of light demanding tree species like *Dalbergia sissoo* and *Acacia nilotica* in sub tropical areas lying in Himalayan region and adjoining plains will further decline because of non availability of optimum light during winter and prevalence of cold waves at the time of new leaves emergence.
- ❖ The mortality of *Robinia pseudoacacia* will further increase because of non-availability of sufficient snowfall in sub temperate and lower temperate regions.
- ❖ The occurrence of frequent cold wave conditions during spring season will not allow the natural regeneration of Sal (*Shorea robusta*) growing in foothills of Himalayas. Because Sal seedlings are highly susceptible to frost damage.
- ❖ Increasing overall temperature and ever widening variation in maximum and minimum temperature will have retrogressive effects on the vegetation of Himalayan region, because of which the proportion of climax species Quercus will decrease and that of conifers will increase.
- ❖ The species like *Taxus baccata* and *Corylus colurna*, which have narrow altitudinal range (7000-9000 feet) and have severe natural regeneration problems will face stiff competition for their survival.
- ❖ Changing climatic conditions in sub tropical regions favors the expansion of *Pinus roxburghii* towards higher altitudes.
- ❖ Flowering in Rhododendron arboretum is reported to be one-2 months earlier (January –February) instead of March-April.

- Early ripening of berries in the Kaphal tree (*Myrica sapinda*, *M. nagi*) from May-June to March-April.
- Hinsalu (*Rubus ellipticus*) have also shown early, but reduced fruiting and an overall reduction in total yield.
  A number of tree species are showing upward shift in their natural latitudinal limits e.g. *Pinus roxburghii* (1800 to 2200m), *Woodfordia fruticosa* (1500 to 2700m), *Boehmeria platyphylla* (1500 to 2200m), *Cotoneaster microphylla* (3700 to 5400m), *Betula utilis* (4200 to 4400m), *Pinus wallichiana* (3000 to 4300m) and Malus *domestica* (2000 to 3000m) (Verma et. al., 2005).
- The species composition in barren, scrub and grasslands has changed. These lands used to serve as source of grazing for domestic animals are now covered with new invasive species like *Lantana, Parthenium, Eupatorium, Polygonum* etc.
- Many plant species, which were recorded in earlier Flora of this region, are not available in the locations mentioned. For instance, *Aconitum heterophyllum, Lilium polyphyllum, Sorbus lanata, Swertia chirayita, Podophyllum hexandrum*, etc. are reported to be frequent occurrence in Himachal hills are not being observed now. Instead, they are found at 600-800 m above and too with shrunken distribution.

Diversity of indigenous crop and livestock varieties is declining; utilization of exotic high-yielding crop and livestock varieties is increasing. Although there is no figure available for agro- biodiversity loss in the region, it is expected to be high. Some idea can be gained of crop diversity loss from this region. In 1882, 48 distinct varieties of rice, and thousands of nondescript varieties, were reported from the Himalaya, displaced now by a handful of high-yielding varieties (HYVs) (Maikhuri *et al.* 1999). The area under diverse traditional food crops has declined substantially too. Modern cultivation has threatened the age-old bonds between local farmers and traditional crops, which include foxtail millet, finger millet, sorghum, lentils, pigeonpea and cowpea. Thirty years ago, up to 75 varieties were grown in the region. Livestock diversity has also suffered due to attempts to increase productivity. One of the major causes of diversity decline is the displacement, even at smallholder farms, by exotic breeds that are better suited for large commercial farming systems but do not fit in the local environment and customs.

On the positive side, biodiversity can help to reduce the effects of climate change on the region's population and ecosystems. It is therefore crucial to conserve biodiversity that is especially sensitive to climate change, preserve habitats so as to facilitate the long-term adaptation of biodiversity, improve our understanding of climate change and biodiversity linkages, and fully integrate biodiversity considerations into mitigation and adaptation Plans. If the threats of biodiversity loss and climate change are tackled together, the prospects for adapting successfully to the challenges of the future will be very much improved. Agroforestry has the potential not only to check the loss of biodiversity but in fact to increase biodiversity at a particular place. Being multi-component nature there is always a scope to increase the diversity. Increase may be in diversity in woody perennials, crop component, pollinators, air borne microbes, and soil micro and macro flora and so on.

1. Agroforestry in the Indian Himalayas

Agroforestry is the most natural way of life in this region, considering the general physiography, vegetation, existing agricultural practices and the attitude of the people. The major benefit that agroforestry can bring to the sloping areas lies in its capacity to combine soil conservation with production function (Dhyani and Chauhan, 1995, Dhyani and Sharda, 2005). The traditional knowledge/ practices and the status of agroforestry in the region have been well-documented (Dhyani *et al.* 2008). The highlights of these documentations speak of numerous traditional and innovative agroforestry practices adopted by the farmers. Potential agroforestry systems (AFS) identified for different altitudinal ranges, slopes and soil depths involving various trees, shrubs, grasses and crop plants for increased biomass production and environmental protection have been described by Sharda *et al.* (2001).

In the Himalayan region, agroforestry is being advocated for arable lands and non-arable degraded lands, bouldery riverbed lands, landslide and landslip stabilization, abandoned mine spoil area rehabilitation and as an alternative to shifting cultivation. The degraded lands in Himalayan region in majority of cases have been formed due to persistent biotic disturbances (excessive grazing, biomass extraction and consequent absence of natural regeneration). In absence of canopy cover, exotic and gregarious weeds invade these areas. Due to their aggressive nature and a highly efficient nutrient extraction pattern the weeds such as *Lantana camara, Parthenium hysterophorus* and *Chromolaema odoratum* in Western Himalayas, and *Mikania macarantha*, *Imperata cylindrica* and *C. odoratum* in northeast cover the lands. Invasion of Lantana camara (up to 1500m above msl) and *Arundinaria falcata* (ringal, 1800-2800 m above msl) has led to complete absence of species regeneration in sal and oak forests. Much of this area can be reclaimed with agroforestry systems like silvi-pastoral for highly disturbed sites and horti-pastoral for moderately disturbed sites.

Traditional agroforestry systems/practices from the region

Traditional agroforestry systems are broadly based on indigenous knowledge and the species are selected as a part of the cultural patterns of the community. The farmers integrate a variety of woody perennials in the crop and livestock production systems depending upon the agro-climatic conditions and local requirements. Some of the examples include the multitier tree-crops combinations in the home gardens of humid lowlands which generate cash income and meet household requirements. For example, combination of alder (*Alnus nepalensis*) and large cardamom (*Amomum subulatum*) in the humid sub-temperate Himalayas is an excellent example of the commercial but traditional agroforestry systems. Deliberately growing of trees like *Grewia, Celtis* etc., on field bunds and systematic plantation of shade trees for tea and coffee plantation are other common examples of agroforestry practices in this region. The shifting cultivation in north-eastern parts of the country is another example of traditional agroforestry, which is in vogue since ages. However, many of these traditional systems have now culminated into simple subsistence agricultural systems in many situations. Since ecological sustainability of most of these subsistence farming systems is being increasingly questioned, agroforestry provides a viable alternative to integrate the indigenous knowledge and experience in promoting these systems and ensure social acceptability and sustainability. Understanding local tree-use practices is a pre-requisite for formulating economically viable and environmentally non-degrading agroforestry systems (Dadhwal *et al.,* 1989). Traditionally, farmer's objective of introducing and maintaining woody perennials in their farming systems is not only to cover the risk of crop failures but also to meet the demands for fuel, food, fruit, fodder, small wood and timber. During the last more than two decades the AICRP on Agroforestry centres have developed agroforestry systems and practices learning from traditional wisdom and based on the identified MPTS for the major agro-ecological regions of Himalayas. They are presented in Table 1.

Agroforestry interventions based on judicious combination of forestry, horticulture, livestock and agriculture with erosion control structures, such as half moon terraces, contour bunds, grassed waterways, gully plugging and bench terracing are helpful from conservation and production point of view. Agroforestry reduces risks and compensates the failures by giving income from products other than crops; thereby, making the entire system reasonably stable These practices help in moderation of microclimate near trees, which benefits field crops. Plantation of trees rows on field boundaries provide shelter from wind, sun or snow which in turn improve yield of crops and provides wood products. Agroforestry systems offer considerable scope of harnessing advantages of growing trees on marginal lands or with crops on agricultural lands. Agroforestry can restore ecological balance while increasing the area both under agriculture as well as forest cover. It is estimated that non-arable degraded lands, covering about 43 million ha in the country, can be brought under various agroforestry systems.

2. Agroforestry Systems for Hills

There are enough evidences to show that the overall (biomass) productivity, soil fertility improvement, soil conservation, nutrient cycling, microclimate improvement, carbon sequestration potential of an agroforestry system is generally greater than that of an annual system although not necessarily greater than that of a forestry or grassland system (Dhyani *et al.,* 2009). Agroforestry for mountain eco-system is an approach of land use that seeks to improve productivity by planting crops and trees, and even the integration of animals simultaneously or sequentially on the same land. Properly designed agroforestry systems protect crops and forage, increase their production, protect soil and water reservoirs, conserve energy, improve systems richness, create additional wildlife habitat and increase landscape diversity.

Agroforestry practices suitable for hills are required for arable lands and non-arable degraded lands, bouldery riverbed land, torrent control, landslide and landslip stabilization, abandoned minespoil area rehabilitation and as an alternative to shifting cultivation.

Arable lands

Agroforestry systems on arable lands envisage growing of trees and woody perennials on terrace risers, terrace edges, field bunds, as intercrops and as alley cropping in the shape of hedgerow type of plantation. To meet the increasing demands of fuel, fodder, lime, timber etc., it is essential to grow agricultural crops either in the alleys formed by rows of trees planted along the contours or by growing trees on the bunds of terraces. *Acacia auriculiformi,s A. catechu, Ailanthus excelsa, Albizia lebbek, A. procera, Anogeissus latifolia, Erythrina indica, Gliricidia sepium, Leucaena leucocephala, Melia azaderach, Moringa oleifera, Morus alba, Robinea pseudoacacia, Sesbania grandiflera, S. Sesban, Salix spp., Syzygium cuminii* and *Thespesia populnea* are good coppice. These trees are not allowed to attain their full height and are managed scientifically/coppiced at a recommended height of 50 cm, from where new off-shoots emerge over a period of time. Integrating trees on the fields act as natural sump for nutrients from deeper layers of soil, add bio-fertilizer, conserve moisture and enhance productivity of the system. The alley cropping with different leguminous trees for erosion control, improving moisture and nutrient availability for increased crop production while maintaining productive capacity of the soil have been developed for different agro-ecological regions. Subabul (*Leucaena leucocephala*) has been most widely used as hedgerow on field bunds for producing mulch material for moisture conservation and nutrient recycling. Alley cropping with *Leucaena leucocephala* was effective for erosion control on sloping lands up to 30%. The contour-paired rows of Leucaena hedge, Leucaena and Eucalyptus trees, and 0.75 m wide grass barrier at 1.0 m interval in maize brought down runoff from 40 to 30% of rainfall and soil loss from 21 to 8 t/ha on 4% sloping land (Narain *et al.,* 1992). Reduction in crop yield

Table 1. Potential agroforestry systems and practices proposed by AICRP on Agroforestry Centres for different agro-ecological regions of India

Centre	System	Agroforestry interventions proposed
SKUA&T, Srinagar, J&K	Agrisilviculture Silvipasture Energy plantation Hortipasture	♦ *Ulmas wallichiana* with arable crops such as pea and maize followed by oats – mung + beans. ♦ Poplar and Salix based systems for cold desert areas of Ladhakh region. ♦ *Melia azedarach, Ailanthus excelsa, Aesculus indica, Gliricidia trianthes, Robinia pseudoacacia, Ulmus wallichiana* are multipurpose tree species. Besides them other tree and grass species e.g. C*ytisus scoporious, Andropogon verginicus* can also be used. ♦ In almond orchards, legume crops (red clovers and white clovers) and grasses such as *Festuca pretense* and *Dactylis glomerata* are recommended as hortipastoral system.
YSPUH&F, Solan	Agrisilviculture Hortisilviculture Silvipasture	♦ *Grewia optiva, Morus alba, Morus serrata, Acacia catechu, Populus deltoides, Toona cilata* with wheat, paddy, vegetables, maize, barley, upland paddy, pulses, potato. ♦ *Populus deltoides, Populus ciliata* with Pyrus malus, Citrus, Small fruits, Kiwi in irrigated areas. ♦ *Grewia optiva, Morus alba, Populus ciliate, Toona ciliate, Pyrus malus, Mangifera indica, Citrus* sp., *Prumus persica, Prunus domestica, Prunus armeniaca* in rainfed areas. ♦ *Morus alba, Grewia optiva, Robinia pseudoacacia, Populus ciliate, Acacia catechu, Quercus leucotrichophora with Setaria anceps, Chloris guyana*, Hy. Napier, *Dactylis glomerata*, Poa sp., Red clover, White clover, *Stylosanthes hamata* etc.
CSWCRTI,Dehra dun	Agrihorticulture Agrisilviculture Silvipasture	♦ *Mangifera indica, Litchi chinensis*, Citrus sp., etc. could be grown in systematic fashion with field crops. Cash crops (*Curcuma longa, Zingiber officinale*) are ideal for peach gardens, *Artocarpus integrifolia*, Musa paradisiacal and Carica papaya can be grown in homesteads. ♦ Principal crops (rice, wheat, maize, etc.) could be grown with MPTs *Grewia optiva, Bauhinia purpurea, Morus alba, Eucalyptus*, etc.) The possible sites

Centre	System	Agroforestry interventions proposed
		for growing trees are field boundaries, terrace risers and in main agricultural fields in a scattered fashion. ♦ Silvipasture systems e.g. *Dalbergia sissoo + Chrysopogon fulvus, Leucaena leucocephala +* Napier */ Panicum maximum* etc. are best for utilizing the degraded lands for productive as well as protective functions.
GBPUAT, Pantnagar	Agrisilviculture (random trees on farm) Block plantation Agrisilviculture Horticulture	♦ Under the canopy of Populus (cl.G3) planted at 5x4m spacing, wheat, turmeric, potato, coriander and radish for seeds were successful. ♦ Wheat yield was relatively higher under *Melia azedarach, Dalbergia sissoo, A. lebbeck* and *Trewia mudiflora* planted at 5x4m spacing in comparison to other trees species.
ICAR RC NEHR, RC Imphal	Agrisilvipasture Agrihortipasture Silvipasture	♦ Napier grass, maize with *Bauhinia variegate, Pinus roxburghii, Schima wallichi,* and *Artocarpus integrifolia.* ♦ *Citrus rotundifolia*, pineapple with napier. ♦ Lemon with guinea grass, rice, bean, groundnut and soybean. ♦ Eucalyptus sp. *L. leucocephola* and *P. pedicellatum.*
ICAR RC NEHR RC, Lembucherra	Agrisilvi- horticulture	♦ Assam lemon is planted in the inter spaces of Acacia sp. and *Tectona grandis.* Turmeric is also grown as inter crop. ♦ Pineapple is planted in the inter spaces of 12 trees such *as A. auriculiformis, M. alba, Gliricidia sepium* etc. ♦ Sesame is a compatible oil seed crop under *A. auriculiformis.*
ICAR RC NEHR, Barapani	Silviculture (250-400) plants/ha Silvipastoral (400 plants/ ha) Agrisilvicultural (400-500 plants/ha) Sericulture based (i)Agri-silviculture (ii)Silvi-hortipasture Agrihorticulture Paddy-cum-sericulture Homesteads and Aquaculture	♦ *Pinus kesiya, Schima wallichii, Cryptomeria japonica.* ♦ *Alnus nepalensis, Schima wallichii, Michelia oblonga* with Setaria /Guinea and native grasses. ♦ *Alnus nepalensis, Paraserianthes falcataria, Michelia champaca, Erythrina indica, Parkia roxburghii, Prunus cerasoides* and Soybean-linseed, Ginger/turmeric followed by groundnut in alternate year. ♦ *Morus alba* (1.80mx0.9m) and groundnut-mustard. ♦ *Morus alba* (0.9x0.9) *Syzygium cumini+P.guajava* (6x4m)/Assam lemon (4x3m)/pear (6x3m) with pineapple in paired rows with fruit trees and native grasses on bunds. ♦ Guava (5x2.5m; 5x5m; 5x7.5m) with Ginger/ turmeric or groundnut/soybean or chillies+frenchbean; pineapple in guava rows + groundnut. ♦ Khasi mandarin (5x2.5m, 5x5m) Assam lemon (4x3m) with Ginger/turmeric or groundnut/soybean or chillies + frenchbean. ♦ *Morus alba* on bunds with Rice-Rice. ♦ Guava and Banana on bunds with groundnut/beans and chillies with Guava on bunds, rice in lowlands, vegetables, and fish in farm ponds.
ICAR RC NEHR, RC Gangtok	Silvipasture Agrisilviculture	♦ *Ficus hookerii + Thysanoleana maxima.* ♦ *Ficus hookerii* + napier ♦ Among 17 fodder trees, *Ficus lacor* gave highest fresh fodder (204 kg/tree) ♦ Ginger, turmeric, large cardamom and Dinanath grass can be grown successfully (up to 11-15m distance) and rice, soybean, fingermillet, Nandi setaria and fine stylo (beyond 15m) from bamboo shade.

could be minimized by shifting the management of trees to contour hedge rows. The sediment deposition along the hedge and tree rows increased considerably with consequent reduction in soil loss. The hedgerows of perennial pigeonpea gave higher maize-equivalent yield and effectively controlled erosional losses. Application of Leucaena before or at harvesting of maize increased moisture conservation and yield of following wheat crop under Doon valley conditions.

Degraded lands

Suitable agri-horticultural systems have been developed for degraded lands of different agro-ecological regions. These systems allow normal cultivation of agricultural crops in the initial 4-5 years, after which, the horticultural crops provide adequate cover to check erosion and provide continuous returns. The fruit plants involving Citrus species, such as kinnow, lemon, sweet orange; and mango, litchi and peach were identified for horticultural development in the degraded lands of Doon Valley (CSWCRTI, 2000). Intercropping of turmeric with kinnow or peach, and cowpea, blackgram and toria with mango and litchi resulted in the highest net returns without causing any adverse effect on the performance of fruit crops. The yields of green pods of cowpea, and seeds of blackgram and toria crops ranged from 1.6-2.1 t ha^{-1}, 0.5-0.6 t ha-1, and 0.4-0.5 t ha-1 respectively in association with mango and litchi in these gravelly lands.

In marginal and degraded lands of Doon Valley, ameliorative effects of agroforestry have been demonstrated (Dadhwal and Tomar, 1999). There was a decrease in soil pH by 0.4 units, bulk density by 0.1 Mg m-3, improvement in organic carbon content by 0.16% and water holding capacity by 1-5% by adopting agroforestry systems.

About 10 million ha in the states of J & K and Himachal Pradesh are a cold desert, which is an unstable and ecologically fragile region. The biotic pressures on the desert vegetation for fuel, fodder and grazing has led to serious ecological degradation. Mid to high altitude zones of J&K has suffered due to faulty land use practices such as cultivation on steep slopes, over grazing, exploitation of natural tree cover which has threatened the sustainability of the ecosystem. A number of agroforestry species found suitable for this area are: *Grewia optiva, Morus serrata, Celtis australis, Robinia pseudoacacia, Ulmus wallichiana, Quercus spp., Bauhinia variegata* etc. Erosion prone areas can be managed by silvipastoral land use. Fodder trees are preferred as they can be lopped during lean periods and roughages supplemented with palatable and nutritious leaves for livestock feeding. *The local inhabitants use Hippophae rhamnoides, an important indigenous multipurpose shrub of the region, as fuel and fodder*. A study conducted in Spiti Valley of Himachal Pradesh revealed that one ha plantation of this shrub can meet the fuelwood needs of about 20 families (ICFRE, 1993). Salix and Poplar based systems are very important for the cold desert areas of the Himalayan region.

Bouldery wastelands

About one-third of the lands in the Himalayan region are bouldery wastelands, which are formed due to excessive erosion, and deforestation on the hill slopes. These lands are virtually devoid of any economic vegetation and can be rehabilitated by establishing silvipastures for production of fodder, fuelwood and fibre to supplement livelihood gathering of resource-poor farmers. Long-term studies have been conducted on silvipasture systems in the highly degraded lands of Shiwalik foothills, ravinous areas and bouldery riverbed lands. In the Shiwalik foothills, silvipasture systems involving *Eulaliopsis binata, Saccharum munja* or *Vetivaria zizanoides* with Acacia nilotica were promising.

Further, *Eucalyptus tereticornis* + *Eulaliopsis binata* has been identified as an economically - viable and eco-friendly system for rehabilitation of these lands.

Studies were undertaken to identify suitable tree and grass species for developing suitable silvipasture systems on the relatively flat, gravelly and bouldery riverine land for biomass production and environmental protection under Doon valley conditions. These technologies aimed at more profitable utilization of vast areas of wastelands for meeting the varied requirements of the people and ecological rehabilitation of the area and to minimize the impact of natural or man-made disasters. The results have indicated the potential of silvipasture systems, such as *Dalbergia sissoo* + *Chrysopogon fulvus; Acacia catechu* + *Eulaliopsis binata*; Eucalyptus hybrid + *Chrysopogon fulvus*; and *Leucaena leucocephala* + Napier / *Panicum maximum* for utilizing the degraded lands for productive as well as protective functions. In a study, four multi-purpose tree species viz., *Albizia lebbek, Grewia optiva, Bauhinia purpurea* and *Leucaena leucocephala* were grown in association with two grass species viz., *Chrysopogon fulvus* and *Eulaliopsis binata*. The findings over a period of 14 years suggested that gravelly and bouldery lands could be effectively utilized by putting them under perennial vegetation for improving soil fertility and biomass production (Vishwanatham *et al.*, 1989; Samra *et al.,* 1999). Biomass production of *Bauhinia purpurea* and *Albizia lebbek* was consistently higher than that of *Grewia optiva* and *Leucaena leucocephala*, despite the fact that survival was lowest in *Bauhinia purpurea* and highest in *Leucaena leucocephala*. *Eulaliopsis binata* showed greater survival and better growth parameters compared with *Chrysopogon fulvus*. Accordingly, the biomass production of *Eulaliopsis binata* (4.6 t ha-1) was considerably higher than *Chrysopogon fulvus* (2.7 t ha^{-1}). The net returns of Rs. 3500/- ha^{-1} yr^{-1} were obtained in Grewia optiva + Eulaliopsis binata followed by Rs. 3400/- in *Albizia lebbek* from these bouldery lands. There was a marked decrease in soil pH and increase in organic carbon, available P and available K in the surface layer due to the growing of the tree species of Albizia lebbek and Leucaena leucocephala compared with Grewia optiva and *Bauhinia purpurea. Chrysopogon fulvus* also decreased soil pH and increased organic carbon, total N and available K in the surface layer compared with *Eulaliopsis binata*, which had a favourable effect on available P status.

Based on these findings, a combination of *Bauhinia purpurea* or *Albizia lebbek* in association with *Eulaliopsis binata* was identified as the most promising for establishing a silvipasture system in the gravelly and bouldery lands of Doon Valley. The area has now been completely rehabilitated, torrents and stream bank erosion are effectively checked and land productivity has increased manifold in these otherwise unproductive wastelands.

Torrent control

Torrents known as 'choes' or 'rao' are common in the foothills of the Himalayan region. The CSWCRTI took up research on torrent training in the early seventies. The research efforts resulted in identifying the cause of the problems and suggesting possible solutions. The package of ameliorative practices included afforestation, grassland development with trenching across the land slope and growing crops on terraced lands. The torrent banks could be effectively protected by planting Salix, Populas and a mixture of grasses. Construction of cut-off drains, providing grassed waterways, gully control structures and other construction works to reduce runoff velocity are ideal for stream bank stabilization.

Landslide stabilization

The young mountains of Himalayan region are prone to landslides and associated mass movement phenomena due to the tectonic activity, fragile ecosystem, torrential rainfall and human interference. Bioengineering i.e. the use of vegetation either alone or in conjunction with other mechanical measures has assumed great significance in landslide control, torrent control, and rehabilitation of minespoil, bouldery lands and for slope stabilization (Dhyani *et al..,*1988; Katiyar *et al.,* 1988; Juyal *et al.,* 1991). At Nalotanala, a 4 ha landslide area on Dehradun - Mussoorie road has been successfully stabilized by bio-engineering measures including agroforestry interventions, such as planting of *Ipomoea carnea, Vitex negundo* and Napier with *Erythrina suberosa, Dalbergia sissoo* and *Acacia catechu.* The area was completely revegetated and rehabilitated within a period of 10 years. The sediment load which was 320 t ha-1 yr^{-1} before treatment reduced to 5.5 t ha^{-1} yr-1 with the improvement of vegetation cover from <5 to >95%. In addition, dry weather flow, which used last hardly for 100 days after the cessation of monsoon, increased to 250 days after the treatment (Sastry *et al,.* 1981).

Minespoil rehabilitation

About 25% of limestone mining is carried out in the Himalayan region. Unscientific mining and over-exploitation of limestone deposits in Doon valley during sixties and seventies following ruthless cutting of forest vegetation resulted in environmental problems rendering mined areas and their surroundings into barren land with stony / boulder debris. The area was hazardously quarried without taking into account the detrimental effects like denudation of the natural vegetation, pollution of air and water resources, blockade of roads, siltation of reservoirs, communication failures, spoilage of good agricultural lands and vanishing of aesthetics and perennial springs. The debris flow from these mines was as high as 550 t ha^{-1} yr^{-1}. The CSWCRTI, Dehradun undertook a research project in a mined watershed of 64 ha near Shahastradhara for developing technologies for rehabilitation of minespoils. Biological measures with proper scientific technologies were undertaken with or without mechanical measures to restore the productivity of land and to maintain aesthetic beauty and visual impact on ecology. MPTS and other plant species were selected keeping in view the economic and ecological considerations. The selected species were native of the area, lime loving and leguminous with better soil binding characteristics. Results have indicated that planting of slips of *Eulaliopsis binata* was ideal on the degraded, steep minespoil areas. Planting of leguminous species, such as *Leucaena leucocephala* and *Peuraria hirsuta* in the minespoil gave foliage rich in N that served as fodder, organic manure, mulch etc. Species, such as *Thysonoleana maxima, Saccharum munja, Pennisetum purpureum, Eulaliopsis binata, Ipomoea cornea* and *Vitex negundo* performed well under geotextiles, viz., Geojute, netlone, Geocell, Geo-grid, Excelsior matting, wire mesh etc. by arresting soil and supporting vegetation on steep slopes. Impact of different biological measures revealed that vegetal cover increased from 10% to >80% over a period of 14 years and the debris flow decreased from 550 t ha-1 yr-1 before treatment to about 8 t ha^{-1} yr^{-1}. Improvement in soil health was noticed during the rehabilitation of the minespoil degraded lands (Dadhwal, 1999). After 14 years of agroforestry measures and other technologies, the pH of the minespoil came down by 0.6 units (8.1 to 7.5), organic carbon increased from 0.13 to 0.42%, whereas CaCO3 content decreased from 54.6 to 31.0 % and bulk density from

1.63 to 1.47 Mg m-3, which showed that planting of MPTS, shrubs and grasses helped in improvement of soil characteristics over a period of time. Further, there was considerable decrease

in the equivalent slope of land from 38% to 19% and the resultant runoff and soil loss with adoption of mechanical and biological measures aesthetics and perennial springs. The debris flow from these mines was as high as 550 t ha-1 yr-1. The CSWCRTI, Dehradun undertook a research project in a mined watershed of 64 ha near Shahastradhara for developing technologies for rehabilitation of minespoils. Biological measures with proper scientific technologies were undertaken with or without mechanical measures to restore the productivity of land and to maintain aesthetic beauty and visual impact on ecology. MPTS and other plant species were selected keeping in view the economical and ecological considerations. The selected species were native of the area, lime loving and leguminous with better soil binding characteristics. Results have indicated that planting of slips of *Eulaliopsis binata* was ideal on the degraded, steep minespoil areas. Planting of leguminous species, such as *Leucaena leucocephala* and *Peuraria hirsuta* in the minespoil gave foliage rich in N that served as fodder, organic manure, mulch etc. Species, such as *Thysonoleana maxima, Saccharum munja, Pennisetum purpureum, Eulaliopsis binata, Ipomoea cornea* and *Vitex negundo* performed well under geotextiles, viz., Geojute, netlone, Geocell, Geo-grid, Excelsior matting, wire mesh etc. by arresting soil and supporting vegetation on steep slopes. The quality of runoff improved considerably and was within permissible limits and the flow became perennial. The treated minespoil sites have now started generating additional reserves of water for irrigation, fuelwood, fodder, fibre and timber on sustainable basis. These techniques have restored the ecology of the area, ameliorated soil characteristics and improved the socio-economic conditions of the local people.

Alternatives to shifting cultivation

Agroforestry systems have been developed using local resources and conservation-based measures in the North Eastern Hill (NEH) region. Research efforts have been made to understand the potential of micro-watershed land use systems as an alternative to shifting cultivation. Suitable alternate land use systems involving agriculture, horticulture, forestry and agroforestry have been designed with the support of local natural resources for almost identical hydrological behaviour as under the natural system. Agriculture with suitable conservation measures resulted in negligible runoff (3.5-5.8%) and soil loss (2.3-3.0 t ha-1), which was far less than 40.9 t ha-1 of soil loss recorded from traditional shifting cultivation areas. Horticulture alone resulted in substantial soil loss which could be reduced by growing agricultural crops in the interspaces. The model landuse suggests utilizing slopes below 50% towards lower foothills and valley lands for agricultural crops and pisciculture, middle slopes between 50-100% for horticulture and top slopes over 100% for forestry/silvipastoral establishment. Combining fine-root system of grasses and legumes, such as *Stylosanthes guyanensis, Panicum maximum, Setaria* etc. and deep-root system of fodder trees, such as alder (*Alnus nepalensis*) in a silvipastoral system stabilizes terrace risers and provides multiple outputs. Silvipastoral system comprising *Alnus nepalensis*, pineapple and forage crops like *Panicum maximum* or *Setaria sphacelata* coupled with *Stylosanthes guyanensis* in 1:1 ratio was found to be a sustainable agroforestry practice in soils having 30-60% slope. Forage yield of 13.5 t ha^{-1} was obtained from the combination of Stylo and Setaria. In addition to this, 2.3 t ha^{-1} litter from *Alnus nepalensis* and 4000 fruits ha^{-1} from pineapple were obtained. This system also restored the fertility of these soils (Chauhan *et al.,* 1993). Similarly, agri-horti-silvi-pastoral system on the hill slopes is another possible intervention.

Agri-horticultural systems involving cultivation of ginger with fruit plants, such as mandarin and guava on mild slopes have been found profitable, besides protecting and conserving the hill soils in the NEH region. Pineapple can be easily associated with multi-purpose trees in paired rows on hill slopes, where it checks soil erosion and gives considerable cash returns within a short period. Under silvi-horti-system with *Acacia auriculiformis* and *Leucaena leucocephala*, pineapple produced a yield of 11.7 t ha^{-1} and 13.4 t ha^{-1}, respectively (Dhyani *et al.*, 1995). Tree-based landuse systems proved suitable where soil depth ranged between 1.0-2.5 m, whereas dairy farming was found profitable under shallow and highly-leached soil conditions (soil depth <0.75 m). These land use systems showed tremendous fertility restoration capacity by protecting soil, improving soil organic matter and consistently replenishing of nutrients. The vegetative barriers with agroforestry species were able to retain 10 to 61 t ha^{-1} yr^{-1} soil, which otherwise could have washed down and resulted in siltation of streams.

In Meghalaya, the most promising agroforestry practices were arecanut + black pepper + pineapple (Rs.42,750 ha^{-1}) followed by arecanut + black pepper (Rs.36,500 ha-1) and pineapple + mandarin (Rs.29,000 ha-1). Accumulation of 2.91% organic carbon was observed under arecanut + jackfruit + black pepper + tejpatra followed by 1.85% under arecanut + betelvine + miscellaneous trees as against 0.78% only in a degraded land within 10-15 years of this practice. A sharp increase in exchangeable Ca, Mg, K and Na was noticed in all the agroforestry interventions over adjoining degraded lands. The exchangeable Al-, potential cause of infertility of these lands disappeared completely within 10-15 years of agroforestry practice (Singh *et al.*, 1994).

Sericulture-based agroforestry systems on sloping areas combine soil conservation with production function and generate income as well as employment. Sericulture-based silvi-horti-pastoral system with mulberry, guava, pineapple (in paired rows) and grasses on bunds was found ideal on the hill slopes (30-45%) with 0.6-1.0 m soil depth. The mulberry plantation was fully established in the first year itself and reached its maximum yielding capacity from the second year onwards. The rice-cum-sericulture system in the lowlands provided frequent cash-returns by harvesting at least 3 cocoon crops at an internal of 3-4 months, besides two rice crops every year (Dhyani *et al.,* 1996). For the foothill and valley land situations, agro-aquaculture system comprising composite fish culture with azolla, rice, vegetables, groundnut and fruit crops was found profitable and provided employment to 2 persons throughout the year, besides ensuring food supply to the family. For the degraded lands in the shifting cultivation areas, contour hedgerow intercropping and Sloping Agriculture Land Technology (SALT) have been advocated (Kothyari *et al.*, 1996). The contour hedgerow intercropping technology is based on modification of agroforestry system in which nitrogen-fixing plants are planted along contour with desired food crops and other useful plants in the alleys. *Desmodium rensonni*, *Tephorosia candida, Indigofera anil, Leucaena leucocephala* and *Crotalaria tetragona* are the suitable hedgerow species. Similarly, for SALT, contour hedgerows are prepared and the space between two rows of hedgerow areas is called a strip. Alternate strips are selected for cultivation during the year and the strips left uncultivated area planted with permanent crops of horticultural and wood value.

Watershed development in Indian Himalayas

Spectacular achievements on sustainable agricultural development through watershed approach at Sukhomajri in the Shiwalik hills, Fakot in the Garhwal Himalayas and Barapani in the NEH region paved the way for launching massive watershed-based programmes in the country in general and Indian Himalayas in particular (Dhyani *et al.,* 2005). Consequently, a large number of integrated resource management projects viz. European Economic Community Project in Doon Valley, World Bank aided Project in Garhwal Himalayas, Indo-German Changer Eco-Development Project in Kangra valley, Department European Economic Community Project in Doon Valley, World Bank aided Project in Garhwal Himalayas, Indo-German Changer Eco-Development Project in Kangra valley, Department for International Development Project in H.P., IDA-Assisted Forestry Research Education and Extension Project, NORAD-Assisted Environment Conservation Programme, Indo-German Bilateral Project, Indo-German Dhauladhar Farm Forestry Project, IDA/USAID National Social Forestry Umberalla Project, USAID Hill Area Land and Water Development Project, World Bank-Assisted Kandi Area Project, World Bank–assisted Swajal Pariyojana (Self Water Resource Development and Management System), Indo-Norwegian Programme on Trout Fish Culture in H.P., and Indo-Danish, Newzealand and German projects on livestock came into being for sustained economic development of the area. The government of India also invested a sizeable amount into many integrated watershed management programmes being implemented by the agriculture, rural development and environmental ministries. In states, departments such as environment (forest), agriculture, rural development and soil conservation are the nodal developments to implement these programmes. These programmes are multi-disciplinary in nature with variable level of participatory development process. The National Agriculture Policy 2000 seeks to promote the integrated and holistic development of rainfed areas through conservation of rain water and augmentation of biomass production through agroforestry and farm forestry with the active involvement of the watershed community. Non-Governmental Organizations (NGO's) are taking keen interest in development of watersheds. In the region, more than 2000 NGOs and other agencies are taking part in various activities some of which are directly related to watershed management.

Agroforestry and Rural Employment Opportunities in hills

A number of agroforestry systems can be developed for different agro-climatic situations involving agricultural crops, legumes, grasses, fruit plants, flowering and medicines plants, vegetables, livestock, etc. with the support of local natural resources. Sericulture, apiculture, fishery, tea, flowering and medicinal plants as component of agroforestry systems have great potential in the region because of its specific environmental conditions and several micro-situations. Marketing of silk cocoon, tealeaves, fish, and mushroom is now being done by co-operatives. These vocations provide rural population on attractive source of income and help to stop their migration, thereby preserving their skills and way of life. Besides, permitting gainful utilization of the vast natural wealth and help arrest forest destruction.

All the watershed programmes emphasize on natural resource management. In NWDPRA, management of land resources under watershed includes cultivated and uncultivated rainfed land under ownership of private land owners, panchayat, revenue department, etc. Here special focus is on IPM, IWM, Farming System Approach (FSA), Low External Input Sustainable Agriculture (LEISA), Agroforestry, Agri-horticulture, Silvipasture, and Animal husbandry. All these components can safely be put under broad based agroforestry systems. These systems have great potential for employment generation as well as biomass production. Dhyani and Sharda, 2005 worked out more than 5.763 million human days yr^{-1} employment from the region if agroforestry systems could be implemented in 75,500 ha area. Agroforestry systems as rural development options for the Indian Himalayas have great potential particularly under watershed, programmes. However, for successful implementation of these options, greater emphasis is needed on the social, economic institutional and policy interventions. Watershed development programmes are being conducted in the region with technical-back-up from National Agricultural Research Systems (NARS) and involvement of local people and voluntary agencies in their implementation. However, the success of watershed approach largely depends on the degree of participation of the local watershed community. The role of participatory process, scope of NGO's and group dynamics of participants is essential for accelerating the growth in Indian Himalayas (Dhyani *et al.,* 2005). Diversification of land use systems is a necessary strategy for providing variety of products for meeting varied requirements of the people, insurance against risks caused by weather aberrations, controlling erosion hazards and potential particularly under watershed, programmes. However, for successful implementation of these options, greater emphasis is needed on the social, economic institutional and policy interventions. Watershed development programmes are being conducted in the region with technical-back-up from National Agricultural Research Systems (NARS) and involvement of local people and voluntary agencies in their implementation. However, the success of watershed approach largely depends on the degree of participation of the local watershed community. The role of participatory process, scope of NGO's and group dynamics of participants is essential for accelerating the growth in Indian Himalayas (Dhyani *et al.*, 2005).

Diversification of land use systems is a necessary strategy for providing variety of products for meeting varied requirements of the people, insurance against risks caused by weather aberrations, controlling erosion hazards and ensuring sustainable production of the land on a long-term basis.

Agroforestry is a viable alternative to prevent and mitigate climate change effects (Dhyani *et al.*, 2009). Agroforestry - a multiple use concept of land management, is also capable of meeting the present challenges of shortage of fuelwood, fodder, fibre, timber, un-employment, environmental degradation, protection and improvement of wastelands and agriculture land. It has immense potential to ensure stability and sustainability in production and to provide ecological and economic security. The agroforestry systems/practices that has potential in the region have been developed by research institutions and being promoted through different programmes (Table 2).

Capacity building for employment generation

In order to implement the various interventions, capacity building through trainings of the stakeholders is essential. The following agroforestry interventions can be integrated in existing farming systems to generate year round employment and ensure high remuneration.

Integration of few of them in accordance with available human resources, technical expertise and market can bring prosperity in the region.

I. Temperate and sub-tropical fruit based Agri-horticulture system

Top working for in situ improvement of fruit plants Silvi-pasture system for community lands

I. Agroforestry with Soil and water conservation technologies
II. Nursery of fruit and multipurpose trees
III. Bamboo based agroforestry systems and artefacts
IV. Biofuel production and processing
V. Livelihood support activities such as lac culture, gum and resin extraction, etc.

Training could be imparted by the competent institutions to the farmers in the field of agroforestry technologies, nursery management, fruit and vegetable preservation, soil and water conservation techniques, biofuel production and other subsidiary income generating avenues. Rope/ basket making and bamboo based artifacts can be promoted through agroforestry systems without hampering crop production and demanding additional resources. Several species suitable for these purposes are identified and production technology available with the AICRP centres. AICRP on Agroforestry centres has developed vegetative propagation techniques of fruit plants and MPTs. Top working techniques of ber, karonda, Aonla, lasoda, etc. have been standardized for in-situ improvement of existing stock. The trainings could be organized in a batch of 20-25 participants. The training programmes need to be developed depending upon the area and broadly for three regions viz. Valley, Mid-hills and Upper hills /cold deserts.

Table 2. **Some indigenous and potential agroforestry systems/practices for the Indian Himalayas and their area of application (Dhyani and Sharda, 2005).**

Agro-climatic zone and AFS/P	**Brief description**	**Areas**
Temperate **Pure silviculture** 1. Mixture of trees of different growth habit.	Poplars and willows, *Ulmus wallichiava*, *Quercus* spp. and *Hippophae rhamnoides*	J&K, Himachal Pradesh and Uttaranchal
Silvipasture 2. Silvipasture	Poplars, willows, oaks with vegetative barriers of *Apluda mutica, Heteropogon, Panicum maximum* and legumes such as clovers etc.	J&K
Agri-silviculture 3. Pine trees with field vegetable crops	Khasi pine (*Pinus kesiya*) with pea, radish, potato, sweet potato, cabbage, turnip, cauliflower, mustard or maize. Pine trees thoroughly pruned to avoid shade effect on the crops.	N.E. Hills
4. Boundary plantation	Poplars and willows with paddy and oats.	J&K, Himachal Pradesh and Uttaranchal
5. Agri-silviculture	Robinea, Ailanthus, Horse-chestnut, Poplar, Salix etc. with maize and mustard.	J&K, Himachal Pradesh and Uttaranchal
6. Agri-silviculture	Poplar and willows with tomato, brinjal, chilly, saagh, capsicum, french beans, potato, knol khol, peas, cabbage, onion turnip, cauliflower, radish and garlic etc.	J&K, Himachal Pradesh and Uttaranchal
Horti-agriculture 7. Plums with vegetables	Plums with pea, radish, cabbage or cauliflower. Trees scattered or on field bunds.	J&K, Himachal Pradesh and Uttaranchal
8. Apple with field/vegetable crops	a) Apple+potoato, b)Apple+barley, and c) Apple+vegetable (Apple+potato is the best intercropping combination in this zone)	Sikkim, Arunahcal in N.E. Hills and J&K, H.P. and Uttaranchal
Horti-silviculture 9. Horti-silviculture	Poplar, willow, horse-chestnut, Robinia and Ailanthus, apple cherry, peach, pear, pomegranate, almond, walnut etc.	Western Himalaya (J&K and H.P.)
10. Horti-silvipasture	Poplar, willow, horse-chestnut, Robinia and Ailanthus, apple, cherry, peach, pear, almond etc. with oats	Western Himalaya (J&K and H.P.)
Horti-agri-pasture 11. Pears with vegetables/ broom grass	Pears with cabbage, cauliflower, beans or broom grass	Sikkim
12. Horti-silvi-agriculture	Poplar, willow, horse-chestnut, Robinia and Ailanthus, apple, cherry, peach, pear, almond etc. with saagh, potato, french beans,	Western Himalaya

	knol khol, onion cabbage, turnip cauliflower, radish, peas, garlic etc.	
13. Kitchen garden	Poplar, willow, horse-chestnuts Robinia and Ailanthus, apple, cherry, peach, pear, almond with saagh, potato, french beans, knol khol, onion cabbage, turnip cauliflower, radish, peas, garlic etc.	Western Himalaya
Horti-agri-pasture		
14. Pears with vegetables/ broom grass	Pears with cabbage, cauliflower, beans or broom grass	Sikkim
15. Horti-silvi-agriculture	Poplar, willow, horse-chestnut, Robinia and Ailanthus, apple, cherry, peach, pear, almond etc. with saagh, potato, french beans, knol khol, onion cabbage, turnip cauliflower, radish, peas, garlic etc.	Western Himalaya
16. Kitchen garden	Poplar, willow, horse-chestnuts Robinia and Ailanthus, apple, cherry, peach, pear, almond with saagh, potato, french beans, knol khol, onion cabbage, turnip cauliflower, radish, peas, garlic etc.	Western Himalaya
Sub-tropical hill zone		
Horti-silviculture		
17. Alder with large cardamom	Alder (*Alnus nepalensis*) and Chilloni (*Schima wallichii*) with large cardamom	Sikkim, Nagaland, Manipur, Arunahcal, Uttarakhand
18. Chilloni with pineapple	Chilloni (*Schima wallichii*) with pineapple	Meghalaya, Manipur
Agri-silviculture		
19. Chilloni with pineapple	Chilloni (*Schima wallichii*) with ginger/turmeric	Meghalaya, Manipur
20. Jhum cultivation	In shifting cultivation areas, selected trees are left to grow during the fallow phase. Common agricultural crops and vegetables are grown in intimate mixture as intercrops.	NEH except Sikkim and Arunachal Pradesh
21. Bun cultivation	Khasi pine, chilloni, etc. retained and crops are grown on raised beds known as buns	Meghalaya
22. Agriculture with alder	Alder on field margins with primary crops of maize, job's tears (*Coix lacryma*), millet, potato and wheat and secondary crops e.g. chillies, pumpkin, taro (Colocasia) etc.	Nagaland
23. Multi-purpose trees on crop lands	MPTS such as Prunus cerasoide, A. nepalensis, Musa, Ficus, Schima wallichii, Artocarpus, Bambusa, Gmelina arborea, Morus alba, etc. scattered on bunds, terrace risers or field boundaries	Nagaland, Meghalaya, Arunachal, Uttaranchal, J&K, H.P.
24. Contour hedgerow intercropping and Sloping Agriculture Land Technology (SALT)	*Desmodium rensonni, Tephrosia candida, Indigofera anil, Leucaena leucocephola, gliricidia, Robinea, Cassia siamea* and *Crotalaria letragona* with crops and fruit plants.	Sikkim, Arunachal, Nagaland and Uttaranchal
Silvipasture		
25. Chilloni/pine with broom grass	Broom grass is cultivated under the trees of Khasi pine and Chilloni	Nagaland, Meghalaya, Arunachal

26. Nevaro with amilloso or Alder	Amiliso (Broom grass) is cultivated with nevaro (*Ficus auriculata*) or utis (Alder)	Sikkim
Sub-tropical hill and plain zone **Agri- silviculture** 27. Apiculture with trees	Tussor silkworm rearing on the leaves of oak (Quercus spp.) and mulberry plants on terrace risers, CH on contour and muga on Som (*Machilus bombycins*) and *Litsea*.	Manipur, Meghalaya, Nagaland, Arunahcal Pradesh, Uttarakhand, Himachal Pradesh
Horti-agriculture 28. Sikkim mandarin (*Citrus reticulata*) with field crops/ vegetable crops 29. Khasi mandarin with pine-apple/vegetables	Intercrops viz. maize-wheat; maize+ginger/ buckwheat/millet/ pulses/ vegetables/beans/radish/ hara simbi/ ricebean; maize+soybean/ millet; ginger+ ricebean; and maize/sweet potato/ millet/ buckwheat /vegetable beans/radish are grown in the orange orchards in Sikkim Mandarin with pineapple/beans/radish/ ginger/turmeric/cole crops in Meghalaya and other States	Sikkim Meghalaya
Silvipasture 30. MPTS with grasses	*Dalbergia sissoo + Chrysopogon fulvus, Acacia catechu + Eulaliopsis binata, Leucaena leucocephola + Napier; Grewia optiva/Bauhinia purpurea + C. fulvus/E. binata.*	Degraded lands in Western Himalaya.
Sub-tropical plain zone **Tree gardens or Homesteads** 31. Fruit trees in kitchen garden or farm boundaries	Tree tomato (*Cyto maddra betacea*), guava, banana and Moringa grown in kitchen garden or farm boundaries	Meghalaya, Negaland, Manipur
Mild tropical hill and plain zone **Multi-storied** 32. Arecanut based Systems 33. Tea with shade trees and betel vine/ black pepper	Arecanut+pineapple+betelvine/blackpepperarecanut and betelvine +pineapple and black pepper. All these systems are practised on the most degraded bouldery lands with high slopes and shallow soil depth conditions. Bamboo drip irrigation is used for watering the plants. Tea cultivation on hill slopes with shade trees such as *Alnus nepalensis, Derris robusta*, silver oak, *Albizia* spp. and betel vine or black pepper	Meghalaya, Tripura Uttarakhand (9000 ha), Arunahcal (560 ha), Manipur (160ha), Nagaland (52 ha), Tripura (6000 ha)
Horti-silvi-pasture 34. Mixed land use	Arecanut+blackpepper+mandarin; arecanut+ jackfruit+mandarin; bamboo+ broom grass+ Schima wallichii; broom grass+tapioca+ sweet potato. These practices are based on the production of	Meghalaya, Tripura

	fruits, nuts, betel leaf integrated with woody perennials.	
Horti-silviculture 35. Fruit trees on degraded lands	Jackfruit+pineapple;mandarin+jackfruit;arecanut+ jackfruit+betelvine	Meghalaya, Tripura
Agri-silviculture 36. Plantation crop combination	Multipurpose trees such as *Prunus cerasoides, alder, banana, Ficus, Schima wallichii, Artocarpus, Gmelina arborea*, mulberry, bamboo etc. scattered on bunds, terrace risers or field boundaries.	N.E. Hills
Horti-silviculture *37.* Coffee and black pepper with hollock and hollong	A recent introduction. Coffee and black pepper cultivated with hollock (*Terminalia myriopcarpa*) and hollong (*Dipterocarpus macrocarpus*) in forest area and with *Erythrina indica* on crop land	Meghalaya, Arunachal Pradesh
38. Home gardens	Intensive integration of MPTS (*Albizia, Gmelma*, Jackfruit, Banana, Papaya, Coconut, Arecanut) with annual crops and small livestock.	Meghalaya, Arunachal Pradesh
39. Small production systems	Silkworm rearing, livestock, honeybee and fish-production in and around homesteads. Composite fish culture in ponds and trees/shrubs lining fishponds, leaves being used as forage for fish.	N.E. and Western Himalayan foot hills.

Future Needs

The analysis presented here is not based on a comprehensive treatment of all aspects of agroforestry research that has happened in the Himalayan region, but it gives a clear identification of the advances made in understanding and appreciation the potential of agroforestry. Owing to increased supply of wood in the market, there has been a significant increase in the number of factories /industries dealing with wood and wood based ventures, particularly in the valley areas of the region. Such industries have promoted agroforestry (through Poplar and Eucalyptus) and contributed significantly in increasing area under agroforestry. Agroforestry promotion for realizing the true potential requires efforts from all the concerned like research institutions, SAUs, forest departments, panchayats, NGOs and farmers. The emphasis needs to be upon creating infrastructure, ensuring quality in planting material, plugging the vacuum of extension network, favourable pricing mechanism including support price system, encouraging public- private partnerships in all spheres of agroforestry among others. Future areas of R&D in agroforestry should emphasise on environmental protection and economic rehabilitation of degraded and otherwise unproductive lands for resource conservation and enhance productivity in the hills.

a. In addition to promoting indigenous agroforestry models, research is required to be done to identify short rotation, high value species that suit the farmers' requirements of planting on marginal lands.
b. Selection of trees that could provide more cash benefit to farmers through their products.
c. Pilot studies on comparative release of carbon from arable, silviculture and agro- forestry land use options and its rational management should be carried out by exploiting wastelands as a source of sink for carbon sequestration.

Diversification of live-fencing and boundary plantation needs to be standardized on sloppy lands as a soil and water conservation option and providing alternate source of food, fodder and fuel in rainfed regions.

d. The role of Nitrogen Fixing Tree Species (NFTS) in integrated nutrient management using VAM and BNF for nutrient recycling and dynamics, root turn-over etc. needs to be worked out under agroforestry systems
e. The potential of agroforestry systems in minimizing soil erosion and loss of nutrients vis-à-vis cultivated lands needs to be scientifically evaluated in different agro-climatic regions to mitigate climate change effects.

The present article concludes that the agroforestry inventions are beneficial in soil amelioration and stabilization of degraded lands of the hill region. More effective and sustainable conservation of soil and water could be achieved with agroforestry-based models. Sustainable development and management of these lands through agroforestry innovations not only meets the multiple needs or food, fodder, fuelwood, fibre, fertilizer, etc. The role of agroforestry in addressing the challenges of livelihood, economic development and environmental management through the approach of integrated farming system mode is thus self-imperative and inclusive.

3. References

Chauhan, D.S., Dhyani, S.K. and Desai, A.R. (1993). Productivity potential of grasses in association with Alnus nepalensis and pine apple under silvi-horti-pastoral system of agroforestry in Meghalaya. Indian J. Dryland Agric. Res. & Dev. 8:60-64.

CSWCRTI (2000). Annual Report 1999-2000. CSWCRTI, Dehra Dun, India.

Dadhwal, K.S. (1999). Arresting environmental degradation of limestone mined lands from North-West Himalayas through agroforestry. In: Sustainable Rehabilitation of Degraded Lands through Agroforestry (Eds. K.R. Solanki, A.K. Bisaria and A.K. Handa) pp. 95-101. National Research Centre for Agroforestry, Jhansi.

Dadhwal, K.S. and Katiyar, V.S. (1996). Land degradation and environmental pollution by mining and landslides. In: Soil Management in Relation to Land Degradation and Environment (Eds. T.D. Biswas and G. Narayanasamy) pp. 114-126. Indian Society of Soil Science, New Delhi

Dadhwal, K.S. and Tomar, V.P.S. (1999). Enhancing production by managing tree roots in an agroforestry landuse system SAIC Newsletter, Dhaka, Bangladesh, 9: 5&7.

Dadhwal, K.S.; Narain, P. and Dhyani, S.K. (1989). Agroforestry systems in Garhwal Himalayas of India. Agroforestry Systems 7(3): 213-225.

Dhyani, S.K. (2003). Role of watershed management in improving forage production. In R.C. Jakhmola and R.K. Jain (Eds.), Sustainable Animal Production. p. 173-207.Pointer Publ. Jaipur, India.Dhyani, S.K. and Sharda, V.N. 2005. Agroforestry systems as rural development options for the Indian Himalayas. J. Tree Sciences 24(1).1-19.

Dhyani, S.K., Chauhan, D.S., Dinesh Kumar, Kushwaha, R.V. and Lepcha, S.T. (1996). Sericulture based agroforestry systems for hilly areas of north-east India Agroforestry Systems 34:1-12.

Dhyani, S.K., Chauhan, D.S., Singh, B.P. and Prasad, R.N. (1995). Tree effect on yield and quality of pineapple (kew) in a silvi-horti systems of agroforestry in NEH region of India. Range Management & Agroforestry, 16(2): 89-93.

Dhyani, S.K., Dadhwal, K.S. and Katiyar, V.S. (1988). Biological measures for rehabilitation of abandoned mine area– preliminary studies. Indian Farming 38(7): 7-10.

Dhyani, S.K., Ram Newaj and Sharma, A.R. (2009). Agroforestry: its relation with agronomy, challenges and opportunities. Indian J. Agronomy 54(3)70-87.

Dhyani, S.K., Handa, A.K. and Uma (2008). Twenty five years of Agroforestry Networking (1983-2008). NRCAF, Jhansi, p. 102.

Dhyani, S.K., Samra, J.S., Ajit; Handa, A.K. and Uma (2007). Forestry to Support Increased Agricultural Production: Focus on Employment Generation and Rural Development. Agricultural Economics Research Review 26(2):179-202.

Dhyani, S.K., Sharda, V.N. and Samra, J.S. (2005). Agroforestry for sustainable management for soil, water and environment quality: looking back to think ahead. Range Mgmt. & Agroforestry 26(1):71-83.

ICFRE (1993). Annual Research Report for 1991-92. Indian Council of Forestry Research and Education, Dehra Dun, India.

Jianchu, X., Shrestha, A., Vaidya, R., Eriksson, M. and Hewitt, K. 2007. ICIMOD Technical Paper, ICIMOD, Nepal.

Joshi, A.K. and Joshi, P.K. 2011. A rapid inventory of indicators of climate change in the middle Himalaya. Current Science 100(6): 833-33.

Juyal, G.P., Katiyar, V.S., Sastry, G., Gurmel Singh and Joshie, P. (1991). Geojute for rehabilitation of steep mine spoil areas Bulletin No. T-26/D-19. CSWCRTI, Dehra Dun.

Katiyar, V.S., Dadhwal, K.S. and Dhyani, S.K. (1988). Soil conservation measures in mine spoil stabilization. In: Wastelands Development and Their Utilization pp. 226-236. Scientific Publications, Jodhpur.

Kothyari, B.P., Rao, K.S. and Palni, L.M.S. (1996). SALT or SWEET for the Rehabilitation of Degraded Lands in the Himalaya. In : Land utilization in the Central Himalayas : Problems and Management options. (Eds. Kumar, K., Dhyani, P.P. and Palni, L.M.S. pp. 323-334. Indus Publishing House, New Delhi.

Maikhuri, R.K., Rao, K.S., Patnaik, S.; Saxena, K.G. and Ramakrishna, PS. (2003). ENVIS Bull.- Himalayan Ecol., 11: 1-9.

Maikhuri, R.K., Rao, K.S., Saxena, K.G. and Semwal, R.L. (1999). Traditional crop-diversity based nutrition & the Prospects for Sustainable Rural Development in the Central Himalaya. Himalayan Paryavaran (The Journal of the Environmental Protection Society) 6: 36.44.

Narain, P., Singh, G. and Joshie, P. (1992). Technological needs of vegetative land protection measures. Proc. 7th ISCO Conference, held in Sydney, Australia, 28-30th September, 1992, pp. 638-643

Samra, J.S., Vishwantham, M.K. and Sharma, A.R. (1999). Biomass production of trees and grasses in a silvipasture systems on marginal lands of Doon Valley of north-west India. 2. Performance of grass species. Agroforestry Systems 46:197-212.

Sastry, G., Mathur, H.N. and Tejwani, K.G. (1981). Landslide control in North-Western outer Himalayas, Bulletin No. R8/D6, CSWCRTI, Dehra Dun.Sharda, V.N.; Dhyani, S.K. and Sharma, A.R. (2001). Role of Agroforestry in Disaster Management. Submitted to Chairman, HPC (DM Plan), DOA&C, Govt. of India, New Delhi, pp.37.

Shrestha, A.B., Wake, C.P., Mayewski, P.A. and D.B.J.E. 1999. J. Climate 12:2775- 27787.Singh, B.P.,

Dhyani, S.K. and Prasad, R.N. (1994). Traditional agroforestry systems and their soil productivity on degraded alfisols/ultisols in hilly terrain. In: Agroforestry systems for Degraded Lands (Eds. P. Singh, P.S. Pathak & M.M. Roy) pp.205-214. Oxford & IBH Pub. Co. Pvt. Ltd., New Delhi.

Verma, K.S. 2007. Climate Change and Its Impact on Farming Systems in H.P. Himalayas: Weather Trends and Carbon Sequestration Potential of Agroforestry. Presented in “Workshop on AICRP on Agroforestry (May 19-21, 2007)” organized by NRCAF, Jhansi at YSPUHF, Solan (H.P.).

Vishwanatham, M.K., Samra, J.S. and Sharma, A.R. (1999). Biomass production of trees and grasses in a silvipasture system on marginal lands of Doon Valley of north-west India. 1. Performance of tree species. Agroforestry Systems 46:181-196.