

Traditional agroforestry in the eastern Himalayan region: Land management system supporting ecosystem services

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Abstract: Large scale land use transition for maximizing the benefits to meet the rising demands for food and other ecosystem services for the well being of the societies has been the main problem confronting sustainable development in the mountain areas. Agroforestry is one of the favoured land management systems in the mountains. This paper analyses the role of traditional large cardamom (*Amomum subulatum*) agroforestry system on enhancing the ecosystem services in the Eastern Himalayas. The large cardamom based agroforestry system is observed to accelerate the nutrient cycling, increases the soil fertility and productivity, reduces soil erosion, conserves biodiversity, conserves water and soil, serves as carbon sink, improves the living standards of the communities by increasing the farm incomes and also provides aesthetic values for the mountain societies. The cardamom agroforestry stored 3.5 times more carbon than the rainfed agriculture showing potential mitigation possibilities of the agroforestry by sequestration of the atmospheric carbon. The agroforestry is an efficient management system where ratio of output to input is more than 13 compared to rainfed agriculture. Cost benefit analysis showed that the cardamom agroforestry is profiting the farmers by 5.7 times more compared to the rainfed agriculture. This agroforestry system is a unique example of the ecological sustenance and economic viability for the mountain peoples while providing goods and services to the downstream users. In the large scale land use change role of the cardamom agroforestry seems quite promising for ecological and economic sustainability.

Resumen: La transición de gran escala en el uso del suelo que persigue maximizar los beneficios y cubrir las crecientes demandas de alimento y otros servicios ecosistémicos para el bienestar de las sociedades ha sido el principal problema que enfrenta el desarrollo sustentable en las áreas montañosas. La agroforestería es uno de los sistemas de manejo de la tierra favoritos en las montañas. Este artículo analiza el papel del sistema agroforestal tradicional de cardamomo (*Amomum subulatum*) en la promoción de servicios ecosistémicos en los Himalaya orientales. Se ha observado que el gran sistema agroforestal basado en el cardamomo acelera el reciclaje de nutrientes, incrementa la fertilidad del suelo y la productividad, reduce la erosión edáfica, conserva la biodiversidad, el agua y el suelo, funciona como un resumidero de carbono, mejora los estándares de vida de las comunidades al incrementar el ingreso de los agricultores y también proporciona valores estéticos para las sociedades de las montañas. El sistema agroforestal de cardamomo almacenó 3.5 veces más carbono que la agricultura de temporal, mostrando así un potencial de mitigación y posibilidades para el secuestro del carbono

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atmosférico. La agroforestería es un sistema de manejo eficiente en el que la relación entre salidas y entradas es más de 13 en comparación con la agricultura de temporal. Un análisis de costos-beneficios mostró que la agroforestería de cardamomo está generando provechos para los agricultores 5.7 veces mayores que la agricultura de temporal. Este sistema agroforestal es un ejemplo único del sustento ecológico y la viabilidad económica para las pueblos de las montañas, a la vez que proporciona bienes y servicios a los usuarios corriente abajo. En el cambio de uso de suelo a gran escala, el papel de la agroforestería de cardamomo parece ser bastante promisorio para la sustentabilidad ecológica y económica.

Resumo: A transição em larga escala no uso do solo com o objetivo de maximizar os benefícios e satisfazer a procura crescente de alimentos e outros serviços ambientais para o bem estar das sociedades, tem sido o principal problema que enfrenta o desenvolvimento sustentável nas áreas montanhosas. A agrosilvicultura é um dos sistemas de gestão de terras favoritos para as áreas montanhosas. Este artigo analisa o papel do sistema agroflorestal tradicional do cardamomo (*Amomum subulatum*) na promoção de serviços ambientais nos Himalaias orientais. Observou-se que o sistema agroflorestal baseado no cardamomo acelera a reciclagem dos nutrientes, aumenta a fertilidade e produtividade do solo, reduz a erosão do solo, conserva a biodiversidade, a água e o solo, funciona como sumidoro de carbono, melhora o standard de vida das comunidades ao aumentar o rendimento dos agricultores e também proporciona valores estéticos para as sociedades de montanha. A agrosilvicultura do cardamomo armazena 3,5 vezes mais carbono do que a agricultura de sequeiro mostrando assim o seu potencial benéfico para o sequestro de carbono atmosférico. A agrosilvicultura é um sistema de gestão eficiente no qual a relação entre as saídas e as entradas é 13 superior ao da agricultura de sequeiro. A análise custo-benefícios mostrou que a agrosilvicultura do cardamomo está gerando benefícios 5,7 vezes superior quando comparado com a agricultura de sequeiro. Este sistema agroflorestal é um exemplo único de sustentabilidade ecológica e de viabilidade económica para as populações das montanhas, proporcionando, ao mesmo tempo, bens e serviços às populações a jusante. Na mudança em larga escala no uso do solo, o papel da agrosilvicultura do cardamomo parece ser bastante promissora para a sustentabilidade ecológica e económica.

Key words: *Amomum subulatum* (large cardamom), *Alnus nepalensis*, carbon stocks, human well-being, nutrient cycling, productivity.

Introduction

Ecosystem services are defined as “the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life” (Daily 1997). A rapid population growth in recent times has increased the pressure on the natural resources such as the available land for sustaining the livelihoods, and with over exploitation and extraction of the natural resources the ecosystems are becoming unsustainable and fragile (Sundriyal & Sharma 1996). Thus, ecosystem service trade-offs arise from management choices made by humans, which can change the type, magnitude,

and relative mix of services provided by ecosystems (Rodriguez *et al.* 2006). Land degradation is among the major challenges confronting sustainable development. As a result, millions of people depending on forests and tree resources for their subsistence have become more vulnerable. The multi-functionality of the agroforestry systems has been realized over the last four decades. Thus, agroforestry system research and development has evolved dramatically with much emphasis on how they function, diversity from local, landscape to regional level, local knowledge systems, economic valuation and environmental services they provide (Beer *et al.* 2005). Agroforestry was recognized by

Intergovernmental Panel on Climate Change as having potential for sequestering carbon as part of climate change mitigation strategies (Watson *et al.* 2000).

Agroforestry has the potential to improve livelihood as it offers multiple alternatives and opportunities to farmers to improve farm production and incomes and also provides productive and protective (biological diversity, healthy ecosystems, protection of soil and water resources, terrestrial carbon storage) forest functions to the ecosystems while protecting the natural environment. It is promoted widely as a sustainability-enhancing practice that combines the best attributes of forestry and agriculture. This practice is now recognized widely as an applied science that is instrumental in assuring food security, reducing poverty and enhancing ecosystem resilience at the scale of thousands of smallholder farmers in the tropics. Therefore, strengthening linkages between knowledge systems using “Community” participatory management approaches is now seen as critical for

sustainable forestry and agroforestry systems (Adhikari *et al.* 2007; Dhakal *et al.* 2007; Ramakrishnan 2007).

Traditional agroforestry systems in the mountains are very close to natural ecosystems as they provide ecosystem services similar to the forests such as the biodiversity, provision of food and fibre, water resources and its purification, climate regulation and carbon sequestration, nutrient cycling, primary production, production of oxygen, and soil formation, and recreation and the cultural services for the well being of the people and society (Fig. 1). Agroforestry systems of land use and management date back to the early origin of agriculture or settled cultivation. However, modern science has shown how agroforestry systems can be designed for deriving the maximum benefit, on an ecologically sustainable basis. These systems integrate crops and/or livestock with trees and shrubs resulting in multiple benefits including diversified income sources, increased biological production, better water quality, and improved habitat for both

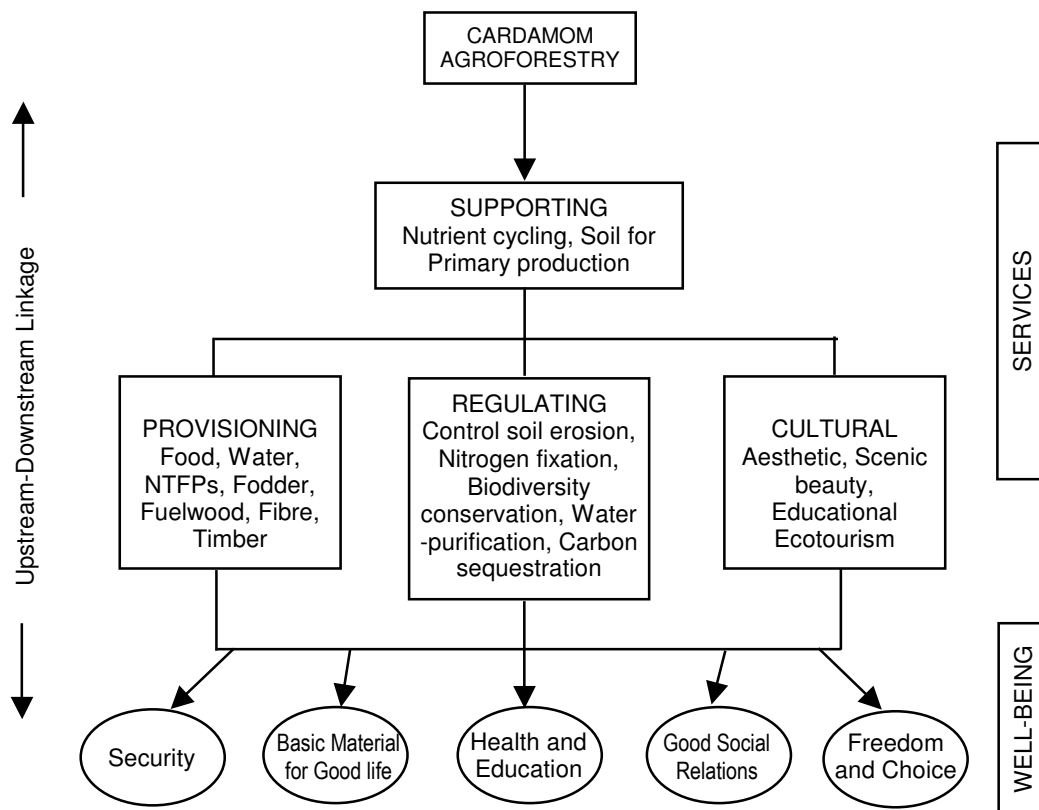


Fig. 1. Environmental services and well-being of both upstream and downstream populations from cardamom agroforestry systems in Sikkim, India.

humans and wildlife. Trees on farms provide both products and services: they yield food, fuel wood, fodder, timber and medicines, and they replenish organic matter and nutrient levels in soils and help control erosion and conserve water. For example, the Himalayan alder (*Alnus nepalensis*) based agroforestry is particularly useful for supplying nutrients such as nitrogen and phosphorus also to the plantations or croplands located downstream (Singh 2002). Consequently an agroforestry system with combination of forestry and agricultural components is an excellent practice where the environmental services are obtained in a sustained manner for both the upland communities and the downstream users.

The eastern Himalayan region also comprises diversity of agroforestry system as an important land use practice. Agroforestry is accepted as one of the sustainable management systems for provisioning functions adopted by the mountain communities in the region. Such systems conserve soil by improving the fertility levels and erosion, provide quality water for local consumption, fodder for livestock, fuel and timber for use as energy and construction materials, and traditional crops for food security. Integration of cash crops in the system gives good economic return that promotes poverty alleviation and contributes to the human well being and good health. One good example of such a traditional agroforestry system is the cultivation of large cardamom as cash crop in the Indian state of Sikkim of the eastern Himalayan region. Such agroforestry systems are unique examples of the ecological sustenance and economic viability for the mountain peoples while providing goods and services to the downstream users.

This paper discusses the large cardamom cash crop based agroforestry systems as a sustainable land production system for environmental management, conservation and economic sustainability in the upstream region as well as providing services for the downstream beneficiaries in the eastern Himalayan region.

Large cardamom cultivation

Large cardamom (*Amomum subulatum* Roxb) is one of the oldest spices known to mankind. This native plant of Sikkim has five wild relatives while

Amomum subulatum is the cultivated species. The crop was first domesticated by the indigenous Lepcha tribe and then by other communities Bhutias and Nepalis of Sikkim and was later passed on to the neighboring Darjeeling district of India, parts of Bhutan and eastern Nepal (Sharma *et al.* 2000). The cultivated cardamom has about 12 local varieties and seven species of wild relatives readapted to different agroclimatic conditions of the eastern Himalayan region. Over the last decades the cultivation of this crop has spread over other Indian north-eastern states of Nagaland (550 ha), Mizoram (35 ha), Meghalaya (35 ha), Manipur (10 ha) and the central Indian Himalayan state Uttaranchal (41 ha) covering a total of 34,252 ha in India (Srinivasa 2006).

In addition to the above mentioned Eastern Himalayan region, large cardamom is widely distributed in the East Asian mainland. The Cambodian cardamom "Siam" (*Amomum krervanh*) grows in wild under the forest cover in Cambodia, Thailand, Vietnam and Laos. *Amomum villosum* is cultivated in China while bastard cardamom (*Amomum xanthiodes*) grows in wild under forest cover in Thailand. Other species of cardamom such as *A. tsao-ko* and *A. aromaticum* are grown in Hoang Lien Mountain Range of Vietnam. These various species of cardamom increase the income of local communities. It has been observed that the effective management of forest resources and conservation of biodiversity through community participation by cultivation of cardamom improves livelihood security in the region (Buckingham 2004).

In the Yunnan Province of China, the plantation of cardamom species such as *Amomum villosum*, *A. tsao-ko* and *A. kravanh* by local ethnic communities has been observed on a commercial scale and the system provides substantial economic return to the communities (Guan *et al.* 2002). *A. villosum* is a native to Guandong province of China and it was introduced to Xishuangbanna of Yunnan Province in 1963. It was planted as understorey medicinal plant in tropical rainforests. A recent research concludes that *A. villosum* can be cultivated in secondary forests to enhance cultivation and conserve tree biodiversity (Zheng *et al.* 2005).

In Laos, *Amomum villosum* is the second largest agriculture export amounting to 400-500 metric tons per year to China for making Chinese

medicine “*sha ren*”. In the remote northern Phongsaly region, *A. villosum* was introduced to 75% of the farmers during 1990s through Rural Development Project of the Lao Government while the species is also cultivated in Bachiang, Pak Xong and Laongam in the Southern Laos (Docourtieux *et al.* 2006).

Cardamom-based traditional agroforestry systems in eastern Himalaya

The large cardamom is a perennial cash crop grown traditionally beneath the natural forest tree cover on marginal lands and slopes. It is a shade loving plant and requires high moisture and is usually cultivated in areas where mean annual rainfall varies between 1500-3500 mm. Some common shade trees for the agroforestry are *Schima wallichii*, *Engelhardtia acerifolia*, *Eurya acuminata*, *Leucosceptrum canum*, *Maesa chisia*, *Symplocos theifolia*, *Ficus nemoralis*, *Ficus hookeri*, *Nyssa sessiliflora*, *Osbeckia paniculata*, *Viburnum cordifolium*, *Litsaea polyantha*, *Macaranga pustulata*, and *Alnus nepalensis*. Hence, large cardamom agroforestry practice also supports conservation of tree biodiversity in the region (Sharma *et al.* 1994). Biodiversity is an important indicator for sustainability, and biologically diversified systems such as cardamom-based traditional agroforestry have a greater capacity for adaptability, ecological resilience and show more sustenance. The agroforestry practice supports highly diverse tree species and tree diversity index in cardamom agroforestry is higher compared to other agroforestry practices in the region (Sharma & Sharma 1997). The trees also support birds and other wildlife which influences the ecological structure and functioning of the agroforestry system.

Majority of cardamom plantations have Himalayan alder (*Alnus nepalensis*) as shade trees since the combination of *Alnus* and cardamom is sympatric and has proved to be ecologically and economically viable. The crop is predominantly cultivated between 600 and 2000 m that covers the subtropical to the cool temperate zones. Farmers take care to grow the crop on steeper marginal and fragile lands so as to minimize the soil erosion and landslides (Sharma & Sharma 1997). *Alnus* also grows naturally on landslide affected sites and being an actinorhizal (nitrogen fixer) plant (Sharma &

Ambasht 1984, 1986), it is a good associate for the cardamom crop. The practice of using nitrogen fixing *Alnus* as shade trees has been adopted by the indigenous communities to maintain the soil fertility and increasing the productivity (Sharma *et al.* 1994). The large cardamom agroforestry has been an advantage to the peoples of Sikkim since a very long time. Its cultivation is an example of how a local mountain niche can be exploited in a sustainable way. This system shows that how an ecological and economical traditional farming practice has evolved indigenously as the main agroforestry practice in the region (Singh *et al.* 1989).

The plant is a shrub by habit and has several tillers consisting of pseudo-stems with leaves on the upper part. Its capsule (fruit) contains about 3% essential oil rich in cineole. A total of 16,949 cardamom holdings have been recorded in Sikkim state, most of which are smaller than 1 ha. About 30% of the total area under cultivation is 1–3 hectares in size. About 1316 ha of reserved forest in Sikkim are being presently used for under-canopy large cardamom cultivation (Sharma *et al.* 2000) while all other plantations are under private land holdings of the farmers. Looking into the increase in the cultivated area of large cardamom, the total area of large cardamom agroforestry has increased by 2.75 times during the past three decades. However, the total cultivated area between 1985 and 2005 has increased by 1.46 times (Table 1). The cash income earned from the crop in Sikkim increased from 1.9 million USD in 1975 to 13.8 million USD in 2005. Sikkim contributes about 50% of the world's production of large cardamom. In Sikkim alone, the area under large cardamom has increased by 135% between 1975 and 1995 (Table 1). Recently degeneration of cardamom is observed mainly due to the viral diseases such as *chirkey* and *phurke*. In Sikkim the cardamom yield has substantially reduced (Sharma 2006). Disease control measures in the form of uprooting and drying of the infected plants and/or either burning or burying of infected plants are commonly practiced (Srinivasa 2006). This crop is widely used as a spice, flavoring agent, confectionaries, making perfumes, and medicines. The major buyer of cardamom is Pakistan while UAE, Iran, USA, Afghanistan, UK, Malaysia, Argentina and Japan are other principal markets in the world.

Table 1. Decadal change in cardamom cultivation area and cash income in Sikkim.

Area/cash	1975	1985	1995	2005
Cardamom agroforestry area ($\times 10^3$ ha)	10.00	20.90	23.50	27.59
Percentage of area under cardamom as against total cropped area	15	17	17	22
Cash income from cardamom (in million US \$ each year)	1.90	5.70	6.40	13.75

Conversion at a fixed rate of US \$ 1 = Indian Rupees 42.

Ecological sustainability

Large cardamom agroforestry system is suitable to the ecological conditions of the region with the provision of high income from the cash crop. The cultivation of perennial large cardamom is a good example of fulfilling the mountain specificities and needs. The soil fertility is continuously maintained through nutrient cycling from the natural tree cover. Ecological sustainability is even greater with cardamom when the Himalayan alder is used as the shade trees, as this tree regenerates naturally on sites affected by landslides (Sharma *et al.* 1998). It fixes atmospheric nitrogen and helps maintain the soil fertility, increases the productivity through faster rates of nutrient cycling and also grows within the same agroclimatic range (600-2500 m) as cardamom. Dry-matter production in terms of biomass production and net primary productivity are higher under nitrogen fixing alder when compared with the natural forest-cardamom plantations despite low tree density in *Alnus*-cardamom plantations (Table 2). The nutrient cycling in terms of standing state and uptake of nitrogen and phosphorus is also enhanced in the stands with alder trees. The agronomic yield (productivity) of large cardamom doubles under the influence of *Alnus* trees (Table 2). The low nutrient use efficiency for both nitrogen and phosphorus also supports the fact that nutrient use efficiency should decrease with increase rates of uptake as an influence of the nitrogen fixing *Alnus* tree (Binkley *et al.* 1992).

The cardamom agroforestry also helps conserve soil and water as it is obvious from the

data available from different farming systems in Sikkim (Sharma *et al.* 2001). Cardamom is well adapted to the local soil conditions. Various data were collected for large cardamom and other crops based on 6 rainfall events. Soil loss (30 kg ha⁻¹) and overland flow (2.17% of precipitation) were low in large cardamom agroforestry compared to other agroforestry types whereas 477 kg ha⁻¹ soil was lost and 9.55% of precipitation was lost as overland flow in the rainfed agricultural systems (Table 3). Hence the system contributes to the regulating services of the ecosystems where soil and water are conserved by reducing the soil erosion and landslides in the mountain slopes to a certain extent. The conservation value for water (81%) and soil (87%) is higher for the cardamom agroforestry system compared to rainfed agriculture (Table 4). A wide range of functions and services from soil fertility maintenance to conservation of soil and water, increasing the productivity and reducing the erosion of soil in this agroforestry proves the system to be ecologically sustainable.

This agroforestry system is self sufficient and does not depend on external inputs. It is less

Table 2. System function of cardamom agroforestry system under nitrogen fixing *Alnus* and forest.

System function parameter	<i>Alnus</i> -cardamom	Forest - cardamom
Biomass (kg ha ⁻¹)	28422	22237
Net primary production (kg ha ⁻¹ yr ⁻¹)	10843	7501
Cardamom capsule production (kg ha ⁻¹)	454	205
Nitrogen		
Standing state in Biomass (kg ha ⁻¹)	395	206
Nitrogen fixation (kg ha ⁻¹ yr ⁻¹)	65	-
Uptake from soil (kg ha ⁻¹ yr ⁻¹)	79	81
Use efficiency*	73	93
Phosphorus		
Standing state in Biomass (kg ha ⁻¹)	32	18
Uptake from soil (kg ha ⁻¹ yr ⁻¹)	13	7
Use efficiency*	823	1151

* Nutrient use efficiency is the ratio between annual net primary productivity and nutrient uptake.

Table 3. Comparison of overland flow and soil loss in different land-use systems in Sikkim.

Land use	Overland flow (% of rainfall)	Soil loss (kg ha ⁻¹)
Forests	3.56	74
Cardamom- agroforestry	2.17	30
Horticulture based agroforestry	4.76	145
Rainfed agriculture	9.55	477

Values are mean of six rainfall events during monsoon

Table 4. Water and soil runoff quantities and conservation values based on three rainfall events.

Agriculture system	Water runoff (%)	Soil loss (t ha ⁻¹)	CV for water (%)	CV for soil (%)
Rainfed agriculture	17	1.26	77	64
Cardamom agroforestry	14	0.45	81	87
Bare-land	74	3.46	-	-

CV=Conservation value calculated using Ambasht *et al.* (1984)

labour intensive and a low-volume (about 250-300 kg ha⁻¹) crop, and has a long keeping quality (non-perishable) which is a great advantage in mountain areas where accessibility and transportation are limited. It meets the adaptive requirements of mountain specificities, such as inaccessibility, by marketable product having long keeping quality, marginality by growing in marginal lands by poor and indigenous peoples, fragility by providing forest cover and perennial agricultural cash crop, and opportunities of increased income resulting from it being a niche cash crop. The freshly harvested cardamom capsules require large amount of fuelwood for curing (drying) which is done in the farm in traditionally made drying kilns. The fuelwood for curing the crop comes from the agroforestry itself. The shade trees actually produce 4500 to 5500 kg ha⁻¹ yr⁻¹, thus offering a welcome surplus for other uses as about 80 to 100 kg of fuel wood is required for curing 100 kg of the cardamom capsules (Sharma *et al.* 1994). The surplus fuel wood produced by the agroforestry is sufficient for both domestic consumption and curing of the cardamom capsules.

As trees play a major role in sequestering carbon, the stocks from different components like

crop, tree, litter and soil were compared between the cardamom-based agroforestry and rainfed agroforestry systems with shade trees like *Albizia*, *Alnus* and mix forest species. *Alnus*-cardamom system comprised 3.5 times more carbon compared to rainfed agriculture. The total carbon stocks when compared in the cardamom-based agroforestry systems showed highest stocks in the *Alnus*-cardamom stands followed by forest-cardamom and *Albizia*-cardamom stands. The *Alnus*-cardamom agroforestry system showed significantly higher floor litter carbon than other stands. Contribution of litter and trees to carbon stocks was substantially higher in *Alnus* dominated stands (Table 5). The contribution of soil carbon was highest in the forest cardamom stands (Rai & Sharma 2004). However, system wise comparison showed higher carbon stocks under the nitrogen fixing *Alnus* combination. Lal (2004) has also mentioned that agroforestry is an option for conserving soil and improving the soil organic carbon pools.

Economic valuation and sustainability

Comparing the two dominant farming systems in Sikkim, the gross household income from different livelihood options was almost double from the cardamom dominant systems (Table 6). The major portion of household income comes from selling the cardamom which is a high value crop compared to other farm produces. The cardamom system is self reliant with no external inputs in the form of chemical fertilizer or manures. The nutrients are available from the accelerated nutrient cycling through litter decomposition from the shade trees (Sharma *et al.* 1997a, b). Large cardamom is a less labour intensive cash crop that requires one time weeding and harvesting as a management practice but often requires periodic monitoring of diseases and pests. For better management, growers carry out gap filling by planting new cardamom and thinning of trees for appropriate density management (Sharma & Singh 2004). Comparing the two major mountain agricultural systems, the input in terms of cost of firewood, labour, manure, seeds and planting stock, it is higher in the rainfed agriculture than the cardamom agroforestry systems. The output in terms of agronomic yield, firewood, fodder and crop

Table 5. Carbon stocks (t ha⁻¹) in rainfed agriculture and cardamom based agroforestry systems in Sikkim.

Agroforestry components	Rainfed agri-culture	<i>Albizia</i> -carda-mom	<i>Alnus</i> -carda-mom	Forest-carda-mom
Crops	4.24	4.51	6.46	1.68
Tree (or cropland weeds)	5.04	9.19	37.25	7.89
Litter	-	1.84	12.06	2.27
Soil (up to 30 cm depth)	37.11	65.27	106.00	121.00
System total	46.39	80.81	161.77	132.84

Note: Stand age of *Albizia*-cardamom was 10 years, and both for *Alnus*-cardamom and Forest-cardamom the age was 20 years

Source: Sharma (1995 and 2003) and Sharma *et al.* (2001)

Table 6. Gross household income (in US \$) from cardamom and rainfed agriculture systems in Sikkim.

Livelihood options	Cardamom dominated system	Rainfed agriculture dominated system
Crop production	144	158
Large cardamom	872	162
Livestock	207	106
Agriculture labour	36	145
Non-agriculture labour	41	31
Service sector	447	239
Business/shop	24	58
All options	1771	899

Source: Sharma & Sharma (1997)

residue are all high in the cardamom system. In a hectare with the total input costs of 123 USD the output was 1619 USD in the cardamom system alone. Therefore, the ratio of output to input is 13.16 in cardamom and only 1.85 in the rainfed agricultural system (Table 7). Cost benefit analysis showed that the cardamom agroforestry is profiting the farmers 5.7 times more compared to the rainfed agriculture. The higher cash return from the *Alnus* systems of agroforestry support its association to be an efficient system for management (Sharma *et al.* 2003). The cardamom system is economically viable benefiting marginal

Table 7. Comparison of inputs and outputs using cash equivalents (in US \$) in cardamom agroforestry and rainfed agriculture. Values are based on one hectare.

Input/Output	Cardamom agroforestry	Rainfed agriculture
Input		
Labour	53	80
Firewood (used for cardamom curing)	40	-
Chemical (fertilizer or pesticides)	-	50
Farmyard manure	-	80
Seed/planting stock	30	100
Input total	123	310
Output		
Agronomic yield	1533	544
Firewood (domestic use)	79	-
Fodder/crop residue	7	30
Output total	1619	574
Output : Input ratio	13.16	1.85

households who depend largely on subsistence farming practices.

Ecosystem services

Supporting and regulating services

Trees play a vital role in almost all terrestrial ecosystems and provide a range of products and services to rural and urban people both within the upstream and downstream regions. As seen in the case of *Alnus*-cardamom agroforestry, the harvested part of the net primary production e.g. the capsules and fuel wood directly results in products that generates income. Comparing the net primary productivity of *Alnus*-cardamom agroforestry with the forest-cardamom stands, the net primary productivity is higher in the stands with the nitrogen fixing *Alnus*. Atmospheric nitrogen fixation by *Alnus* and the mobilization of the stored organic and inorganic soil reserves increase the quality and quantity of nutrient uptake and return. This leads to increased nutrient cycling in such systems which directly enhances the productivity. Table 2 clearly shows that in the phosphorus limited soil as it is in most parts of the Himalayan soil types, the agroforestry with nitrogen fixing trees such as *Alnus* not only

increases the levels of phosphorus in the soil but also helps in solubilization of phosphorus for the uptake by plants. This mechanism consequently restores farm soil fertility to enhance food crop production that contributes to food security.

Such agroforestry system is also efficient in controlling the soil erosion and landslides as the trees and the understorey crop help in binding the soil through its roots and mycorrhiza. Specially the plantations, being largely located at the slopes, help in controlling erosion and retain the sediment thus helping in conservation of soil. The soil loss from the *Alnus*-cardamom agroforestry is lower when compared with other land-use types (Table 3). Increasing infiltration capacity of soils, water cycling and uptake by transpiration contribute to the efficient water conservation in the systems (Sharma *et al.* 2001). The conservation value for water in the cardamom agroforestry was found to be 81% which is higher compared to the rainfed agriculture system (Table 4). The shade trees provide a buffered environment at ground level contributing to microclimate regulation while agroforestry patches along the mountain slopes regulate it at a landscape level. The agroforestry also acts as a habitat for pollinators and biological agents of pests and disease organisms.

At the global scale, maintenance of biological diversity, green house gas regulation and climate regulation are the best known functions of such agroforestry systems. The cardamom agroforestry system shows a net storage of carbon in the soil and the biomass. The carbon storage in cardamom agroforestry is higher than the rainfed agriculture systems. However, it is comparatively higher in *Alnus*-based agroforestry than the other farm-based agroforestry systems (Table 5). The agroforestry helps to reduce deforestation and pressure on woodlands by providing fuel wood from the agroforestry itself. The fuel-wood demand of cardamom drying during harvesting is availed through thinning of alder trees. The *Alnus*-cardamom agroforestry system satisfies diversity of farmers' needs simultaneously without the need for external inputs or heavy labour, while also stabilizing riparian zones and providing watershed protection (Zomer & Menke 1993).

Cardamom-based agroforestry and farm-based agroforestry in a traditional agriculture system support *in situ* conservation and augmentation of

agro-biodiversity through indigenous adaptive management and innovations.

Spiritual and cultural services

The Sikkim Himalaya is considered as the sacred landscape traditionally called the *Ney-Pemathang* or *Shangri-La* (the hidden paradise on earth) and is worshipped in various religious-traditional festivals such as *Pang-Lhab-Sol* (mother deity Khengchendzonga) and *Tendon-Lho-Rum-Faat* (Sacred Tendong Hill in Sikkim). The indigenous communities of the region are culturally rich and consider Mt. Khangchendzonga and other mountain peaks as the abode of deities. The entire plants, animals, agroforestry systems, soil, water, air etc. are considered sacred and culturally important (GIAHS 2007; Ramakrishnan 2001). For the indigenous and traditional societies of Sikkim and the region, agroforestry plays an important role in cultural and spiritual traditions. Hence it provides recreation and spiritual services for the culturally diverse ethnic communities of the region. The management functions and benefits of such agroforestry in Sikkim provide ample opportunities for social harmonization between the different ethnic communities like *Lepchas*, *Bhutias* and *Nepalis* and strengthen traditional institutions such as Dzumsa (a traditional governance system of the villages of north Sikkim).

The forested slopes in the mountains have always been attractive to the tourists and visitors. There are cases of home stays by tourists for bird watching and trekking to the higher mountains in parts of cardamom cultivated areas in north Sikkim. The agroforestry is also a common destination for the students for understanding conservation, soil management and ecosystem services. The values of such systems are also deep rooted in the culture of the Sikkimese peoples who regard forests and its resources to be sacred. Farm-based agroforests are continuous with wider natural forest areas that also provide suitable habitat to Himalayan flagship species and corridor for their seasonal movement.

Provisioning services

The large cardamom agroforestry system has positive sustainability implications in terms of the quality of life and equity. This production option

has increased the economic levels of the farmers leading to improved lifestyles and good health. Good education, access to health services, better homes and enhancement in the living standards of the people have led to improved physical, mental and spiritual health of the farming community who were depending on the subsistence farming for their livelihoods and were generally poor. The improved access to medical facilities has in general reduced the maternal death rates and also the infant death rates. Hence increased production and high value (income) obtained from the large cardamom crop has been able to reduce the poverty levels of farm families (Sharma & Sharma 1997) and to maintain associated traditional agriculture. With better life and improved nutrition the problems related to health and impacts of hunger and chronic illness has lessened. The indicators for good health and improved lifestyles are seen as increased number of children going to school, proper housing, increased facilities like electricity, good medical care, transport and all the modern assets (Sharma & Sharma 1997).

Conclusions

Traditional agroforestry systems in the Eastern Himalaya show the way to reconciling short-term food and livelihood needs with long-term environmental conservation and enhancement. Most environmental degradation in the world today is located in low-income countries, where it is rural and poverty-based. Example of the cardamom-based agroforestry in the eastern Himalayan region provides a clear picture on the improved economic status of the rural poor as well as better management option for the mountain ecosystems. Complementing to the Millennium Ecosystem Assessment (MA 2005) approach, the cardamom agroforestry system offers multifunctional attributes and ecosystem services such as provisioning, supporting, regulating, and cultural and aesthetic services. Such traditional agroforestry management system is necessarily an indigenous approach and apparently successful than several modern approaches of plantation forests and monocultures elsewhere in the other regions. Such agroforests in the cultivated areas and forests in the wilderness are comparable for their common services. Proper management of traditional agroforestry provides maximum

benefits for the livelihoods and well being of the indigenous mountain communities as well as sustainable functioning of the ecosystems for deriving continuous and sustainable benefits both for the upstream and downstream communities in the region.

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