Chapter 18
Values and Services of Nitrogen-Fixing Alder Based Cardamom Agroforestry Systems in the Eastern Himalayas

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Abstract Recent challenges for sustainable development are linked to large-scale land use transition and its impact on forest-dependent populations. Alternatively, agroforestry practices offer multiple opportunities to farmers to improve farm production and incomes; they also result in productive and protective forests functions. Large cardamom (*Amomum subulatum*) cultivation with N_2-fixing Himalayan alder (*Alnus nepalensis*) as a shade tree in the Eastern Himalayas is one such alternative agroforestry practice. Performances were analyzed for cardamom agroforestry *with* N_2-fixing alder (alder-cardamom), *without* alder (forest-cardamom), and with an age series of alder-cardamom between 5 to 40 years. Alder tree association accelerates the cycling of both nitrogen and phosphorus, and more than doubles production and yield. While increasing soil fertility, alder-cardamom agroforestry also conserves soil and water, and sequesters atmospheric carbon. This leads to ecological sustainability in mountain watersheds. It also provides a high aesthetic value and draws upon cultural, recreational and educational values that are harnessed by local communities as non-farming employment opportunities in ecotourism. Ecosystem services provided by cardamom agroforestry contribute to the well being of the upland people and at the same time profit the beneficiaries downstream.

Keywords *Alnus nepalensis*, *Amomum subulatum*, biodiversity, nutrient cycling, carbon flux, ecosystem services

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18.1 Introduction

The conversion of forests into other forms of land use has been the general trend in mountainous areas. Such changes in land-use have been conspicuous in recent decades in the Himalayan region (Rai et al. 1994). Forest-dominated watersheds have been converted into agrarian watersheds. This type of conversion was induced by an increasing population pressure and the limitations of productive agricultural land (Rai and Sharma 1998). The goal of forested watershed management is the rational utilization of land and water resources, with minimal disturbance to natural resources (Sundriyal et al. 1994). Land management in catchment areas of mountainous regions like the Himalayas essentially relates to the ecosystem services provided by these areas to upland and lowland people. Such ecosystem services specifically involve the conservation of soil and water, the protection of land from soil quality deterioration, and the conservation of water for drinking and other farm uses. Maintenance of these services is of great importance in achieving sustainable and optimum productivity of land use systems (Sharma et al. 1992). Soil on steep slopes with upland farming systems low in tree cover, such as those associated with more intensive agricultural practices is vulnerable to erosion and fertility reduction (Rai and Sharma 1995). The recent challenges in the field of sustainable development are linked to the degradation resulting from large-scale land use, and meeting the growing demand for food. The majority of the population who depend on forest and tree resources for their subsistence have become vulnerable. In such a situation, agroforestry offers multiple opportunities to farmers while also improving farm production and income, and providing productive and protective forest functions.

This chapter discusses a traditional practice of agroforestry with multiple opportunities to farmers in areas subject to land-use change, i.e., large cardamom cultivation with N_2-fixing alder. The practice has been a boon for the mountain populations in the Eastern Himalayas by providing economic benefits, ecological sustainability and ecosystem services (Sharma et al. 2000). Likewise, it has proven to contribute to integrated natural resource management, i.e., a management approach aimed at increasing agricultural production in a sustainable manner (Izac and Sanchez 2001; Lambin and Geist 2003).

18.2 Study Area and Alder-Cardamom Agroforestry

The Eastern Himalayas is spread over a wide spectrum of ecological zones and has a diverse socio-economic potential. It harbours three of the world’s 34 biodiversity hotspots, with an array of unique plants and animals. The five major farming systems operative in the region are: (1) pastoralism, (2) agro-pastoralism, (3) mixed farming systems, (4) shifting cultivation and (5) commercial cash crop cultivation (see Photo 18.1; Sharma and Kerkhoff 2004).

Photo 18.1 Mountain mixed farming system in the Eastern Himalayas (©E Sharma)

Most of the case studies presented here were carried out in an agro-climatic range of 800–1,800 m from the north East Indian state of Sikkim. The study area is in the Indian monsoon region with a subtropical-temperate climate and with three main seasons: winter (November–February), spring (March–May) and rainy (June–October). The mean monthly temperature ranges from a maximum of 14°C to 24°C and a minimum of 5°C to 15°C, and rainfall from 2,500 to 3,500 mm. Relative humidity varies between 80 percent and 95 percent during the rainy season, and down to 45 percent in spring.

Large cardamom (*Amomum subulatum* Roxb.) is the most important perennial cash crop in the Eastern Himalayas, covering parts of Eastern Nepal, Sikkim and Darjeeling in India, and Southern Bhutan. Recently, its cultivation has spread to the northeast Indian states of Nagaland (550 ha), Mizoram (35 ha), Meghalaya (35 ha), Manipur (10 ha) and the central Indian Himalayan state of Uttaranchal (41 ha), and covers a total of 34,252 ha in India (Srinivasa 2006). *Amomum subulatum* belongs to the Zingiberaceae family, and the species cultivated in Sikkim has six local varieties that are suitable for cultivation at different elevations and are adaptable to various factors such as water deficit and frost. Cardamom is predominantly farmed between 600–2,000 m elevations. The plant is a shrub and has several tillers consisting of pseudostems with leaves on the upper part. The inflorescence (spike) appears on the rhizome where the pseudostem shoots up. It is mainly a cross-pollinated crop, although it is capable of self-fertilization. The capsule (fruit) is used as spice or condiment and contains about three percent essential oils and rich in cineole (Gupta et al. 1984). The harvested capsules are cured in traditional kilns.

A total of 16,949 cardamom holdings have been recorded in Sikkim State, most of which were smaller than one hectare. About 30 percent of the total area under cultivation was one to three hectares in size (Sharma et al. 2000). The cardamom agroforestry practice relies on a smallholder farmer engagement system.

Photo 18.2 Alder cardamom agroforestry in Sikkim, Eastern Himalayas (©E Sharma)

Cardamom is a shade-loving crop, grown under forest cover. Himalayan alder (*Alnus nepalensis* D. Don) is the most common species used as a shade tree in cardamom farming (Photo 18.2). Himalayan alder, henceforth called alder, regenerates naturally on landslide affected, freshly exposed and degraded sites. It is grown in forestry, agroforestry like cardamom, shifting cultivation in northeast India, and as a nurse tree in *Cinchona* (medicinal plant) plantations. Alder is a useful associate tree capable of fixing nitrogen efficiently with *Frankia* symbiosis (Sharma and Ambasht 1984). The altitudinal range of the Himalayan alder is sympatric with the agro-climatic range of large cardamom farming. It provides fuel-wood for both cardamom-curing and domestic use. Trees attaining more than 25 to 30 years of age provide timber for either domestic or commercial purposes. The majority of the 30,039 ha area under cardamom cultivation in Sikkim and Darjeeling have alder as the shade tree.

In this chapter, cardamom-based agroforestry systems in an age series of 5, 10, 15, 20, 30 and 40 year old stands will be discussed. In addition, both systems with N_2-fixing alder (alder-cardamom) and systems without alder (forest-cardamom) will be looked at and described.

18.3 Ecosystem Services

The cultivation of agricultural crops with trees in the form of an agroforestry system results in a variety of food and tree-based products (Sharma and Sharma 1997). In addition, when practised in mountainous areas, it provides communities in both upstream and downstream areas with various vital ecosystem services. Based on the Millennium Ecosystem Assessment (MA 2005), the ecosystem services arising from alder-cardamom agroforestry system can be classified into four categories:

(a) Supporting services which are evident from the system's positive impact on productivity, nutrient cycling, nitrogen fixation, energy fixation and nutrient use efficiency
(b) Provisioning services which are evident from the system's yields of cardamom, firewood, fodder and other products
(c) Regulating services which are evident from the system's contribution to soil and water conservation, soil fertility, carbon storage and flows, and a favourable microclimate
(d) Cultural services which are evident from the system's aesthetic, educational and recreational benefits

In the sections below, the various ecosystem services associated with alder-cardamom cultivation in the Eastern Himalayas will be discussed based on the authors' extensive research experience in the region. Furthermore, the efficiency in delivering these services will be described and compared for agroforestry systems with and without N_2-fixing alder, and also for systems with stands of different age.

18.3.1 Productivity, Yield and Energy Efficiencies

The performance of alder-cardamom systems was much higher in terms of productivity and agronomic yield, compared to the forest-cardamom systems (Table 18.1). Alder actually influenced the system by its fast growth which contributes to higher total biomass, and also by enhancing cardamom performance as illustrated by greater tiller numbers, basal area and biomass (Sharma et al. 1994). The agronomic yield of cardamom increased 2.2 times under the alder canopy. Similarly, the comparative study on the impact of standing age (5, 10, 15, 20, 30 and 40 years) on the cardamom crop and the alder trees associated revealed that net primary productivity was the highest (22 t ha^{-1} $year^{-1}$) in the 15-year-old stand and the lowest (7 t ha^{-1} $year^{-1}$) in the 40-year-old stand (Sharma et al. 2002a). Agronomic yield of cardamom peaked between 15 and 20 years of age. Cardamom productivity doubled between the 5 to 15-year-old stand and then decreased with plantation age. It reached a minimum in the 40-year-old stand. The performance of cardamom in association with alder remained ecologically and economically beneficial until the plantation was 20 years old. This suggests that the re-plantation cycle should begin around this age for sustainable management practice. Cardamom being a shade-tolerant plant does not perform well when the canopy opens, as observed after 30 years of age. Ageing could also play a role in the decreasing performance of both the crop and the associated alder.

Studies of energy distribution and flow rates determined for various components of the alder-cardamom and forest-cardamom agroforestry systems highlighted that

Table 18.1 Productivity, yield and nutrient dynamics of large cardamom agroforestry under alder and mixed tree species (After Sharma et al. 1994)

Parameters	Alder-cardamom	Forest-cardamom
Biomass (kg ha^{-1})	28,422	22,237
Net primary production (kg ha^{-1} year^{-1})	10,843	7,501
Agronomic yield (kg ha^{-1} year^{-1})	454	205
Nitrogen		
Standing state in biomass (kg ha^{-1})	395.15	205.26
N_2-fixation (kg ha^{-1} year^{-1})	65.34	–
Uptake from soil (kg ha^{-1} year^{-1})	78.49	80.56
Retention (kg ha^{-1} year^{-1})	56.12	49.55
Return to soil (kg ha^{-1} year^{-1})	83.67	29.23
Exit through agronomic yield (kg ha^{-1} year^{-1})	4.04	1.78
Use efficiency*	73	93
Back-translocation from senescent tree leaf (%)	3.85	17.49
Phosphorus		
Standing state in biomass (kg ha^{-1})	32.357	17.900
Uptake from soil (kg ha^{-1} year^{-1})	13.178	6.517
Retention (kg ha^{-1} year^{-1})	6.328	3.840
Return to soil (kg ha^{-1} year^{-1})	6.146	2.347
Exit through agronomic yield (kg ha^{-1} year^{-1})	0.704	0.330
Use efficiency[a]	823	1151
Back-translocation from senescent tree leaf (%)	22.62	31.37

[a] Nutrient use efficiency is the ratio between annual production and nutrient uptake.

net annual fixation was 1.57 times greater in alder-cardamom (221 × 10^6 kJ ha^{-1} year^{-1}). As for the net energy allocation in the under-storey, large cardamom crop was much higher (45 percent) in the alder-cardamom system than in the forest-cardamom system (31 percent) (Sharma R et al. 2002). Such figures clearly show that N_2-fixing alder is a better associate-shade-tree than mixed tree species, and creates the conditions for a higher energy allocation in the cash-crop system. In absolute terms, net energy allocation in cardamom crops was 2.3 times greater under the alder-cardamom system, as opposed to the forest-cardamom system. In capsule terms the increase was 2.2. Floor-litter energy build-up was conspicuous due to more litter production and accumulation in the alder-cardamom system with 1.6 times more than in the forest-cardamom system.

The Energy Conversion Efficiency (ECE) at the autotrophic level is expressed as a percentage and is defined as the ratio between the energy captured by vegetation and the photo-synthetically active radiation that reaches an area over a certain period of time (Sharma and Ambasht 1991). The ECE of the alder-cardamom system (1.87 percent) was higher than for the forest-cardamom system (1.19 percent). The range of 1.8 to 3.5 percent ECE in the age series of Himalayan alder (Sharma and Ambasht 1991) and 1.8 to 4.2 percent in red alder stands in Canada (Smith 1977) indicate that the 1.87 percent obtained in the alder-cardamom system is within the expected range. Rawat and Singh (1988) reported an ECE of 1.1 percent in oak forests of the central

Himalayas, which is comparable to the mixed tree species forest-cardamom ECE value of 1.19 percent. The ECE contribution of large cardamom was much greater in the alder-cardamom system (0.85 percent) than the forest-cardamom system (0.36 percent). The Energy Fixation Efficiency (EFE) is the annual net energy fixation per unit energy of leaf, and the Energy Accumulation Ratio (EAR) is calculated as the energy stored in the system divided by annual net energy fixation (Sharma et al. 2002). The EFE and EAR of the alder-cardamom system were slightly lower than that of the forest-cardamom system. The alder-cardamom system showed lower EAR, resulting from less energy accumulation in the perennial components of alder trees and also a greater annual turnover in the form of leaf and twigs of tree and cardamom components. This reveals that there are higher energy dynamics in the alder-cardamom system compared to its forest-cardamom counterpart. The EFE may be expected to decrease with increasing rates of fixation because the availability of other resources (such as water or nutrients) may become limited and will constrain production. The EFE in the alder-cardamom based agroforestry systems was generally consistent with this hypothesis: it decreased - and was lower compared to the forest cardamom system – due to the influence of N_2-fixing alder trees (3.29 GJ GJ^{-1} leaf energy $year^{-1}$ in alder-cardamom and 3.70 GJ GJ^{-1} leaf energy $year^{-1}$ in forest-cardamom). Yet, the EFE contribution of large cardamom was greater in the alder-cardamom system (3.20 GJ GJ^{-1} leaf energy $year^{-1}$) than in the forest-cardamom (3.07 GJ GJ^{-1} leaf energy $year^{-1}$) system. Energy efficiency in N_2-fixation decreased with plantation age, ranging between 58–103 g N_2 fixed 10^4 kJ^{-1} energy in the pure age series of alder stands (Sharma and Ambasht 1991), which is comparable to 68 g N_2 fixed 10^4 kJ^{-1} energy in the alder-cardamom system.

The results of the alder-cardamom system's age series showed that annual net energy fixation was highest (444×10^6 kJ ha^{-1} $year^{-1}$) in the 15-year-old stand, being 1.4 times the 5-year-old stand and 2.9 times the 40-year-old stand fixation (Sharma et al. 2002a). Regression analyses suggest that younger plantations are more productive for both cardamom and alder, with inverse relationships between stand age and production efficiency, energy conversion efficiency or energy utilized in nitrogen fixation, and a positive relationship between production efficiency and energy conversion efficiency. The energy dynamics also support the earlier finding concerning the alder-cardamom system's sustainability by adopting a 15 to 20 years rotational cycle.

Cultivation of cardamom is a relatively low input cash crop. The main requirements are labour and firewood for curing the cardamom capsules. The outputs include agronomic yield, fodder and firewood from trees. The quantum of energy input and output for the alder-cardamom system was about twice the quantum for the forest-cardamom system (Table 18.2). The ratio of output to input produced lower values for the alder-cardamom system. However the cash income from this system was more than double the cash income from the forest-cardamom system, and also the cost-benefit analysis gave better results for the former alder-cardamom system. Both the quanta of energy and higher cash return for the alder-cardamom agroforestry system support the idea that the integration of alder trees in cardamom plantations is an efficient management system.

Table 18.2 Annual input and out of energy and cash in cardamom based agroforestry systems Sharma R et al. 2002)

Input/output	Energy ($\times 10^4$ kJ ha^{-1})		Cash (US$ ha^{-1})	
	Alder-cardamom	Forest-cardamom	Alder-cardamom	Forest-cardamom
Input				
Weeding	2.1	4.2	2.8	5.6
Harvest	8.4	4.2	11.2	5.6
Post-harvest	42	21	56	28
Fire-wood collection	13	6	17	8
Fire-wood used in curing	1,064	465	35	17
Total	1,129	501	121	65
Output				
Agronomic yield	920	411	2,112[a]	954[a]
Fire-wood extraction	3,087	1,486	101	56
Fodder	–	596	–	7
Total	4,007	2,493	2,213	1,017
Output:Input ratio	3.55	4.98	18.23	15.67

Human labour per hour was calculated at 0.15 × 10^4 kJ (Freedman 1982)

[a] Calculated at US$4.65 per kilogram of cardamom and cash conversion @ US$1 = Indian Rs. 43.

18.3.2 Nitrogen Fixation and Nutrient Use Efficiencies

Nitrogen accretion through biological fixation following acetylene reduction assay, and then applying the C_2H_2: N_2 conversion factor of 2.4: 1, was used to estimate nitrogen fixation (Hardy et al. 1973; Sharma and Ambasht 1988). In pure plantations of Himalayan alder, the annual accretion was highest (117 kg ha^{-1} year^{-1}) in the seven-year stand and lowest (29 kg ha^{-1} year^{-1}) in the 56-year stand (Sharma and Ambasht 1984, 1988; Sharma et al. 1998a). The Himalayan alder fixed 65 kg nitrogen ha^{-1} year^{-1}, benefiting the associated cardamom in the alder-cardamom system (Sharma and Purohit 1996). In the age series of the alder-cardamom agroforestry system, nitrogen fixation ranged from 52 to 155 kg ha^{-1} year^{-1} (highest at the age of 15-years) suggesting a substantial input of nitrogen into the system by alder (Sharma 2001).

The nutrient use efficiency is the ratio of the annual net primary productivity and the nutrient uptake. The nitrogen use efficiency was 73 and 93; phosphorus was 823 and 1,151 for the alder-cardamom and forest-cardamom stands respectively (Table 18.1). In the case of the age series of the alder-cardamom systems, the nitrogen use efficiency was 98 for the five-year-old stand and 81 for the 40-year-old stand. Similarly, the efficiency use of phosphorus decreased with age, being 2,439 for the 5-year-old stand and reaching a minimum value of 1914 for the 40-year-old stand. The average phosphorus use efficiency in all aged stands was approximately 25 times greater than the nitrogen use efficiency (Sharma et al. 2002b).

A drop in nutrient use efficiency should be expected with ageing tree-crop systems as the utilization of a given nutrient (i.e., the nutrient uptake) increases over the years while the availability of other resources (such as water, energy, or light) becomes more limited which, in turn, will increasingly hamper production (Melillo and Gosz 1983; Bloom et al. 1985). Thus as Himalayan alder plantations age the nitrogen and phosphorus use efficiency will decrease. The latter trends are confirmed by Sharma (1993). Binkley et al. (1992) have further reported that in its use of nutrients, the red alder (*Alnus rubra*) is much less efficient than conifers. The lower nutrient use efficiency of alder trees is however beneficial to other crops in alder tree-crop associations such as cardamom because of the generally greater availability of such nutrients related to the systems' faster nutrient cycling.

18.3.3 Biogeochemical Cycling

The nitrogen and phosphorus concentrations in the tissues of alder trees were higher than those of forest mixed tree species (Sharma et al. 1994). This finding is consistent with the higher concentrations of nutrients found in the red alder, compared with conifers in mixed stands (Binkley 1983; Binkley et al. 1984). Both nitrogen and phosphorus re-translocation from leaf before abscission was lower in alder than mixed tree species. This was because of the higher availability and uptake of these elements in the alder-cardamom system. The general concept of an inverse relationship between availability and conservation is clearly applicable to alder-cardamom and forest-cardamom agroforestry systems. The higher availability of nitrogen and phosphorus for the alder trees resulted in lower re-translocation which is indicative of its poor conservation strategy. However, this strategy is beneficial for the associated crops in the alder tree plantations, i.e., cardamom.

The nutrient re-translocation of senescent alder leaves was positively related to stand age for nitrogen, but negatively with phosphorus. The nitrogen re-translocation in young alder trees was minimal because it was sufficiently available through fixation. However the demands for nitrogen increased with age while the contribution from fixation decreased, causing greater translocation. In the case of phosphorus, its need for tree growth was high in younger stands where effective re-translocation was recorded (Sharma et al. 2002b). Yet, its need and re-translocation decreased with increasing stand age. The alder thus displayed contrasting physiological behaviour for nitrogen and phosphorus at different ages; it was mostly governed by the demand and availability of these nutrients.

The annual uptake and return of nitrogen to the soil in the alder-cardamom stand was higher than the forest-cardamom stand, which can be attributed to nitrogen fixation by the alder tree (Table 18.1). The rates of phosphorus uptake and return through litter-fall and decomposition were also higher in alder-cardamom than the forest-cardamom stand. This was probably a result of an increase in the rate of phosphorus supply, attributable to geochemical and biological factors influenced by the alder. Potential geochemical factors could be rhizosphere acidification (Gillespie and Pope 1989) and biological factors could be rooting depth (Malcolm et al. 1985), soil enzyme activity (Ho 1979) and organic chelates (Ae et al. 1990).

The total uptake of nutrients in the age series of alder-cardamom systems varied from 90 to 239 kg ha^{-1} year^{-1} for nitrogen and from 4 to 10 kg ha^{-1} year^{-1} for phosphorus (Sharma et al. 2002b). Values were lower for nitrogen and higher for phosphorus when compared to the monoculture of the same species of alder in the region (Sharma 1993). Rawat and Singh (1988) estimated the nutrient uptake in a Himalayan oak forest to be 230 kg ha^{-1} year^{-1} for nitrogen and 13 kg ha^{-1} year^{-1} for phosphorus. These comparisons show that pure alder forests have higher nitrogen and lower phosphorus uptake, but that in the mixed stands, cardamom nitrogen uptake decreases while phosphorus uptake increases. The low phosphorus uptake in pure alder stands was attributed to a negative effect of alder on the phosphorus economy, mostly by increasing soil acidity (Sharma 1993). This caused phosphate to react with iron and aluminium to form less soluble phosphate compounds (Brozek 1990; Sharma et al. 1997). Furthermore, a heavy accumulation of organic matter in soils of pure alder stands could have shifted phosphorus from a plant-available pool to an organically bound pool (Sharma 1993). The combination of alder with cardamom is a system in which nitrogen and phosphorus uptakes are balanced, unlike in either pure stands of an N_2-fixing species such as alder, or a non-N_2-fixing species.

The nitrogen and phosphorus cycling in the cardamom agroforestry system appeared to be very malleable (flexible) under the influence of the N_2-fixing alder. Binkley et al. (1992) have also reported that alder results in a generally higher uptake and return of all nutrients, and a greater magnitude of malleability of nutrient cycles are consistent with the findings from the alder-cardamom system. We have observed that the agroforestry system was more productive when alder was integrated into the system, resulting in faster rates of nutrient cycling. The poor nutrient conservation, low nutrient use efficiency and the malleability of nutrient cycling in alder systems make the alder tree an excellent associate that promotes higher availability and faster cycling of nutrients.

18.3.4 Biodiversity Values and Conservation

Biodiversity is an important indicator for sustainability. Biologically diversified systems have a greater adaptive capacity for resilience and show greater sustenance. The cardamom is native from Sikkim in the Eastern Himalayas, and the occurrence of five species of wild cardamom (*Amomum linguiforme*, *A. kingii*, *A. aromaticum*, *A. carynostachym*, *and A. dealbatum*) shows high genetic reserves. *Amomum subulatum* is a cultivated species of cardamom and its cultivation system supports a highly diverse range of shade trees (Sharma and Sharma 1997). Our study supported this since up to 23 species were found. The Shannon and Weaver diversity index of trees in a cardamom dominated system was 4.1. This indicates that there is a fairly good composition of trees providing fodder and firewood to farming families. Most of the cardamom agroforestry have alder as shade trees. However, small patches are maintained with mixed trees so as to meet the fodder requirements of households.

Table 18.3 General bird characteristics in three gradient forests with and without cardamom in Sikkim (Nakul Chettri, unpublished)

Bird variables	Alder-cardamom	Forest-cardamom	Natural forest without cardamom
Species recorded	48	40	50
Species per sample (mean + SE)	5.9 ± 0.2	7.0 ± 0.5	5.1 ± 0.5
Individual per sample (mean + SE)	23.6 ± 1.7	28.3 ± 3.6	24.4 ± 2.7
Shannon Weiner's diversity (H')	2.9	3.1	3.4
Margalef's species richness	12.2	10.6	12.6

This enhances the richness of tree species in a cardamom dominated system. Trees from cardamom agroforestry have multiple uses for farmers, such as fodder, firewood, timber, materials for field implements and residues for animal bedding. These trees also support birds and other wildlife, which has a direct bearing on the ecosystem structure and enables it to function in a sustained manner.

A study of bird characteristics was carried out in three gradient forests in the Khecheopalri and Yuksam areas of west Sikkim: (1) a natural forest without cardamom, (2) a forest with cardamom and (3) an alder forest plantation with cardamom. The general characteristics of the bird community revealed that an alder-cardamom field is an equally good habitat for biodiversity as natural and mixed forests (Table 18.3). A greater richness of bird species and diversity was observed in the natural forest without cardamom, and the species richness in the alder-cardamom stand was also greater than in the mixed forests with cardamom. There were no significant differences in the variables of these three gradient forests. Interestingly, a higher number of species per sample was observed in the alder-cardamom field where insectivores (flycatchers, laughing-thrushes, woodpeckers) and omnivores (drongos, crows, mynas) were the dominant bird species. In a promising surrogate, the pattern of species richness, diversity and the guilds of birds are indicative of the habitat's quality (Anand et al. 2005; Fleishman et al. 2005; Padoa-Schiopa et al. 2006). Since most of the alder-cardamom fields in Sikkim are contiguous to the natural forest, they have a dual function being a feeding habitat on the one hand, and leading to a well developed habitat mosaic which enhances overall biodiversity on the other hand (Chettri et al. 2005). Our results revealed that alder-cardamom is equally good for forest birds, particularly insectivores and omnivores. Also, the high species richness compared to the mixed forest is mainly due to the openness of the upper strata that creates visibility for feeding species. If age groups of alders are maintained so as to enhance different succession stages, then diversity might also be enhanced as reported by Shankar Raman et al. (1998).

18.3.5 Soil and Water Conservation

The overland flow (percentage of rainfall during the rainy season) as estimated in temperate and subtropical forests, cardamom agroforestry, mandarin agroforestry, traditional agriculture areas and fallow land, was the highest (9.6 percent) in the traditional agriculture area and the lowest (2.2 percent) in cardamom agroforestry (Rai and Sharma 1998). The amount of soil loss from cardamom agroforestry was also the lowest, although it proved to be slightly higher than in temperate forests. Records on soil organic carbon, total nitrogen and total phosphorus showed the same trend, with the lowest losses for the cardamom system.

In another experiment, with five dominant types of crops or vegetation (maize, finger-millet, mixed cropping, cardamom, broom grass), covers and bare land were compared so as to determine the *in situ* soil and water conservation values. The data showed here that the lowest losses of water and soil were recorded for the cardamom fields. Likewise, the conservation of both water and soil in cardamom fields was 81 percent and 87 percent respectively (Sharma et al. 2001).

Soil fertility levels have a considerable influence on plant productivity. A comparison between the cardamom dominated system and the maize-potato dominated system revealed higher levels of soil nutrients, particularly of organic carbon and total nitrogen in the cardamom dominated system (Sharma and Sharma 1997). The soil erosion rate measured during the rainy season was about 16 times lower in the cardamom agroforestry system. The loss of nutrients through soil erosion and overland flow suggest that the cardamom agroforestry system provides a much better protective cover. The low volume of soil erosion and consequential low nutrient loss indicate that the cardamom system is ecologically viable when compared to the maize-potato dominated system. Measurements of the distribution of the incidental rainfall into the various pathways revealed that the canopy interception was much higher in the cardamom system. The amount of incidental rainfall contributing to overland flow was only 2.17 percent in the cardamom system, whereas 9.2 percent in the maize-potato system. These values suggest that the cardamom system retains more water from incident rainfall in its various sub-components than the maize-potato system. This was attributed to the presence of trees in the cardamom systems.

18.3.6 Carbon Budget and Flux

Globally, changes of land-use are transforming land cover at an accelerating rate. In mountain ecosystems, such changes are closely linked to the issue of sustainable socio-economic development. Since this can affect essential elements of natural capital such as climate, soils, vegetation, water resources, and biodiversity, land transformation may result in wide ranging changes, many of which are significant on a global scale. These changes include an increase in greenhouse gases and potential global warming, the loss of biodiversity and soil resources, and also other regional impacts which contribute to climate change. In the mountains, watersheds can be considered to be functional units of natural resource management for sustainable development. Understanding the dynamics of watershed functions requires knowledge about physical characteristics such as hydro-ecological links between land uses, resource dimensions and socio-economic conditions. Socio-economic demands and natural resource use are interactive (Rai and Sharma 1998; Sharma et al. 1998b). Increasing stresses on the use of natural resources have an impact at the watershed level which can also result in a cumulative impact at a regional level. Carbon is an important indicator when studying the mechanisms of change in watershed functioning. Therefore, cardamom agroforestry is becoming an important land management practice which is related to economic activity. Its role in climate change could be assessed using carbon as an indicator.

The land-use change over 13 years (1988–2001) in the Mamlay watershed resulted in a net release of 305 × 10^3 t of carbon into the atmosphere (Rai and Sharma 2004). The reduction of forest biomass contributed to 119 × 10^3 t of carbon being released by vegetation and 186 × 10^3 t being released by soil, amounting to a release of about 8 t of carbon from a hectare of land every year in the watershed. The stock of carbon in vegetation and soils in the watershed amounted to 577 × 10^3 t in 2001 (Table 18.4). A comparison of cardamom agroforestry with mandarin and open cropped areas revealed that carbon stocks per unit were five times greater in the cardamom agroforestry system. This system provides an opportunity to sequester substantial amounts of atmospheric carbon and mitigate greenhouse gases. Soil carbon sequestration, as a means of mitigating climate change, was reported by Lal (2004) to be substantial, and the carbon sequestration in the soils of cardamom systems was likewise substantial.

18.3.7 Aesthetic Values

Sikkim in the Eastern Himalayas has established itself as a recommended destination for contemporary tourists in recent years (Rai and Sundriyal 1997). The scenic beauty, rich biodiversity, friendly people and rich culture attract two million tourists every year from all over the world. The mixed ethnic groups (Lepcha, Bhutia and Nepali) who reside in the area have extensive traditional knowledge blended with their culture and religion, which has lead them to be great nature lovers. Inspired by the Sikkim Biodiversity and Ecotourism project (Sharma E et al. 2002), the state is taking a leading role in diversifying and promoting ecotourism with ‘Home Stays’ in remote areas as ‘model villages’.

Table 18.4 Area under different land use and carbon storage in the Mamlay Watershed in Sikkim (Rai and Sharma 2004)

Land use/cover	Area (ha)	Carbon storage (t C ha^{-1})	Area-weighted carbon storage (×10^3 t C)
Temperate natural forest dense	160	191	107
Temperate natural forest open	982	86	304
Subtropical natural forest open	362	90	80
Cardamom agroforestry system	115	47	35
Mandarin agroforestry system	17	6	3
Open-cropped area temperate	413	9	19
Open-cropped area subtropical	506	8	29
Total of land use	2,555	–	577

The cardamom agroforestry landscape is rich in biodiversity and has a high aesthetic value for ecotourists. Its wilderness and natural settings are maintained by agroforestry and cardamom farmers who have a extended traditional knowledge. These areas encourage activities such as bird watching and trekking to the higher mountains through cardamom forests. The Ecotourism and Conservation Society of Sikkim have reported that Home Stay destinations such as Kewzing in the south, Yuksam in the west, Dzongu and Pastanga in the north of Sikkim which have a substantial area under cardamom cultivation are being promoted as a part of an ecotourism package.

18.4 Conclusion

Cardamom is a perennial cash crop grown beneath the forest cover on marginal lands in the Eastern Himalayas. Cardamom growers in smallholdings predominantly use N_2-fixing alder as a shade tree. Cardamom is a low volume, high value and non-perishable crop. Furthermore, it is non-nutrient exhaustive and demands little input while giving high returns in the form of an agroforestry system. The combination of alder and cardamom in an agroforestry system has shown to generate both an economically and ecologically sustainable land use system. The values and services of cardamom agroforestry are enormous, especially when grown under N_2-fixing alder as a shade tree. The efficiencies of alder in terms of energy fixation, production and nutrient use and alder's accelerating effect on nitrogen and phosphorus nutrient cycling have a beneficial impact on cardamom and thereby to the ecosystem as a whole. The cardamom system also provides non-farming opportunities with additional income from home stays and ecotourism as a result of valuing landscapes towards wilderness. Biodiversity values and the conservation of species, soil and water are highly relevant in the context of current regional and global demands for ecosystem services, which are fulfilled by the cardamom system as a potential farming practice that combines cash crop with trees. Alder in the cardamom system sequesters carbon efficiently and the proposed rotation cycle of 15–20 years for alder-cardamom plantations would result in a continuous contribution to carbon sequestration. Thus, the higher productivity and carbon fixation rates of the alder-cardamom system would contribute to the mitigation of climate change.

The ecosystem services resulting from multi-functionalities of N_2-fixing alder and cardamom agroforestry systems in the Eastern Himalayas will enhance the well being of the upstream and downstream beneficiary communities. This would also ensure the supply of ecosystem services to the wider region and for future generations.

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