STUDY AREA, CARDAMOM AGROFORESTRY AND STAND CHARACTERISTICS

3.1 Prelude

The Himalaya (Sanskrit *Hima-* snow, *Aalaya-* house) constitutes a unique geographical and geological entity comprising diverse social, cultural and environmental set up. It is a cradle of unique and important biodiversity elements known for their economic and ecological importance. The growing concerns for deteriorating environment sustainability and formulation of appropriate land-use policies in planning research and developmental activities over the last four decades seem to have cause and effect arguments, and are plunging very fast towards environmental and socio-economic collapse. These unwitting influences have been manifested in the form of deforestation, landslides, down-stream flooding, uncontrolled population growth, poverty and malnutrition and poor management strategies. Progress towards these goals can, in principle, be monitored through out-come oriented codes. Anthropogenic stress on natural ecosystem has triggered large-scale disasters throughout the Himalaya. Undirected spread of subsistence agriculture (for per capita increase) to support the growing undernourished population and corresponding increase of grazing pressures that out-strip the carrying capacity of the forest, continue to abridge supportive ecosystem by various means.

Management practices can do much to conserve or improve biological resources in the Himalayas. The dynamic accomplishment of an ecologically sound and environment friendly, new green revolution is possible only when rural farming families learn to optimally manage their valuable geo- as well as bio-resources.

3.2 The Sikkim Himalaya

The traditional definition of the Himalaya, *sensu stricto,* is that great range of mountains that separates India, along its north-central and north-eastern frontier, from China (Tibet), and extends between latitudes 26^0 20′ and 35^0 40′ North, and between longitudes 74^0 50′ and 95^0 40′ East. The region extends from the Indus Trench below Naga Parbet (8,125 m) in the west to the Yarlungtsangpo-Bramhaputra gorge below Namchee Barwa (7,756 m) in the east, covering the political administrative regions of Afghanistan, Pakistan, India, Nepal, Bhutan, and China (Ives and Messerli 1989). The Himalaya lying in the Indian territory stretches over a length of about 2,500 km and a width of 220−300 km covering partially or fully 12 states/provinces of the Indian Union with the Himalayan kingdom of Nepal and Bhutan. It has been classified into five major geographical divisions′ viz. (a) The eastern Himalaya (Sikkim-Darjeeling-Bhutan and Arunachal Pradesh), (b) The Central Himalaya (eastern and central Nepal), (c) The Western Himalaya (Kumaon-Garhwal, Himachal Pradesh, Western Nepal), (d) North-West Himalaya (Kashmir-Afghanistan), and (e) The North-West Himalaya (Sino-Tibet). This is the highest and youngest mountain system formed out of the bed of the Tyeth

Sea during continental drift sometimes by the end of the tertiary period. The Indian Himalaya covers a total geographical area of approximately 591000 km^2 and is inhabited by about 51 million persons (Rao and Saxena 1994) with a multiple ethnic composition. Geographically speaking the snow clad mountainous range of the Eastern Himalaya and the highly precipitous hilly terrain of Himalayan amphitheater happens to be at a closer proximity to the Bay of Bengal to receive more rainfall than Central and Western Himalayas. The vividly marked tangled series of interlacing ridges with indifferent gigantic mountainous barriers and diversified vegetation green cover , is geomorphologically varied with immense climatic differences even at a closer distance.

Sikkim or the "New House" is situated in the eastern Himalaya (88^0 03′ 40″ to 88^0 57′ 19″ East longitude and 27^0 03′ 47″ to 27^0 07′ 34″ North latitude) sandwiched between the Himalayan kingdoms of Nepal and Bhutan in the west and east, bounded by the vast stretches of Tibetan Plateau on the North and shares southern border with Darjeeling Gorkha Hill Council of West Bengal. The mountain terrain is spread over 7096 km^2 with elevations ranging from 250–8,595 m above msl. Administratively, there are 440 villages, eight towns and four districts and is a cornucopia of four major ethnic groups' viz. *Lepcha (s), Nepalese, Bhutia (s)* and *Limbu (s).*

The climate of the state varies from cold temperate and alpine in the northeast to subtropical in the south. The main livelihood option of the people is agriculture. The state abounds by more than 6000 plant species and more than 4000 species are flowering plants. About 12% of the land is available for cultivation and the main occupation of the hill people is farming. The net state domestic product of Sikkim at constant prices increased by three times from 1981 to 1991 and per capita income doubled during the period. The state earns about 47% of its GDP from agriculture (Anonymous 1981).

3.3 Large cardamom

3.3.1 Agroforestry

Large cardamom locally called "alainchii" is believed to be one of among the oldest spices known and its Ayurvedic preparations dates back to 6th century BC as mentioned by Sashruta. It was known to Greeks and Romans as "*Amomum*" during the 4th century BC and was recorded by Theophrastus the Greek philosopher. The aboriginal inhabitants of Sikkim- *The Lepchas*- were believed to be the first to collect cardamom capsules from natural forests, and these forests eventually converted into ownership and the crop was domesticated.

The seeds are sometimes administered orally for curing certain ailments and acts as carminative; stomachic, diuretic, an effective cardiac stimulant and is a remedial medicine for throat and respiratory troubles. The seeds contain about 3% essential oil rich in cineole (Gupta *et al.* 1984), which is used as flavoring agent and spice.

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 ha large (Sharma and Sharma 1997; Sharma E *et al.* 2000). Figure 1 shows the major cardamom growing areas of Sikkim.

The cultivation area of large cardamom has increased by 2.3 times in the past 20 years. Large cardamom is the most perennial cash spinner native crop of Sikkim grown mostly in private holdings. However, about 1316 ha of the reserved forest in Sikkim is still used for under-canopy large cardamom cultivation on lease to farmers with no rights of cutting the trees (Sharma *et al.* 1994). The crop usually grows as understorey vegetation below the tree canopy and requires an annual rainfall of 1500–3500 mm. During the last 5-6 decades, a large area of agricultural land has been converted to *Alnus*-cardamom agroforestry using monocultures of N_2-fixing *Alnus nepalensis* as shade tree.

3.3.2 Local cultivars and ecological amplitude

The cultivated species is *Amomum subulatum* Roxb. and belongs to the family Zingeberaceae. Seven wild species such as *A. linguiforme, A. kingii, A. aromaticum, A. corynostachyum, A. dealbatum, A. costatum* and *A. plauciflorum* are naturally occurring in the region. The cultivated species has six local cultivars (varieties) suitable for cultivation at different elevations and adapted to various other environmental factors such as water deficit and frost. The common occurrence of local cultivars grown in Sikkim varies according to their altitudinal adaptability. Local varieties such as 'Ramsai', 'Sawney', 'Bharlng' and 'Ramla' are cultivated above 1500 m whereas 'Sawney', 'Chibey' and 'Ramnang' are grown within 1000–1500 m and 'Golsai', and 'Saramna' below 1000 m elevations.

In large plantations of the cardamom agroforestry the shade tree is N_2-fixing Himalayan alder (*Alnus nepalensis* D. Don). Some other common shade trees are *Schima wallichi, Engelhardtia spicata, Eurya acuminata, Leucosceptrum canum, Maesa chisia, Symplocos theifolia, Ficus hookeri, Nyssa sessiliflora, Osbeckia paniculata, Viburnum cordifolium, Litsaea polyantha, Macaranga pustulata* etc. Large cardamom agroforestry thus supports conservation of tree biodiversity in the region though the use of *Alnus*-cardamom systems has recently proved more profitable.

3.3.3 Economics

Only 12.3% of the land in Sikkim is available for cultivation, including currently used and other fallow land. Forest cover account for 41.9% while a large area of 25.4% is barren and uninhabited. About 26,734 ha area is under cardamom cultivation in Sikkim while about 3,274 ha area is under cardamom plantation in adjoining Darjeeling District of West Bengal (Spices Board, Government of India 2001).

The greatest percentage increase of cultivated land was recorded for cereals, followed by large cardamom, oil seeds, vegetables, oranges, pulses, ginger, and potatoes. Percentage increase in state production in the past 20 years clearly show that crops such as cereals, vegetables, ginger, and potatoes performed very well. The percentage contribution of large cardamom production was proportionally small, as it is low volume crop that nevertheless has high economic value. Large cardamom's share in the state's gross income was proportionally very high: 16.58% in 1995–1996, which was second to the 31.14% contribution of cereals. Of the total gross income of the state, large cardamom contributed more than 80% in 1975–1976; this decreased to about 58% in 1985-1986 and to about 38% in 1995–1996.

The gross income from large cardamom cultivation in Sikkim increased from US$ 1.9 million in 1975–1976 to 5.7 million in 1985–1986 and 6.4 million in 1995–1996 (conversion at a fixed rate of US$ 1 = Rs 42). In recent years, the contribution of ginger has increased tremendously, but the net income from large cardamom is still higher. A study that compared two systems, one dominated by large cardamom and the other by maize and potatoes, showed that household income and per person per day income were almost double in the large cardamom system (Sharma and Sharma 1997).

The cash-benefit analysis after three years of plantation of *Alnus*-cardamom crop is given in Table 3.1. Large cardamom is a perennial crop that gives yield form 3rd year of plantation. In the first year the plantation around Rs. 25000 ($538) per hectare is required for planting material and labour. Refilling of gaps and weeding requires Rs. 3500 ($75) per hectare in the second year. After this, from third year onwards weeding, harvest and post-harvest labour costs are the only cash inputs required for the system.

The cash-benefit analysis shows that large cardamom provides excellent income until 15- to 20-year of plantation. The timber and fuel-wood monetary return by the harvest of *Alnus* tree before replanting with a rotational cycle of 20-year would be around Rs. 576000.00 ($12387) per hectare. This is in addition to cash income from large cardamom after 3-year onwards.

3.3.4 Ecological sustainability and future perspective

Besides its high-income value and low demand in labour, large cardamom is also a low-volume and non-perishable crop; this is a great advantage in an area where accessibility and transportation are restricted. Furthermore, cardamom agroforestry is almost a closed system that does not depend on external inputs.

The cardamom crop is well adapted to the local soil conditions and soil loss (30 kg ha^{-1}), overland flow (2.17% of precipitation), and nutrient loss (nitrogen 0.41 kg ha^{-1}; total phosphorus 0.02 kg ha^{-1}, organic carbon 1.86 kg ha^{-1}) were very low in large cardamom agroforestry compared to other forming practice (Rai and Sharma 1988). The ecological sustainability is even greater with cardamom when shade tree used is the Himalayan alder (*Alnus nepalensis*), which regenerates naturally on landslide-affected areas and grows within the same agroclimatic range of cardamom. The agroforestry under the influence of *A. nepalensis* is more productive because of higher nutrient cycling rates. The poor conservation and low nutrient use efficiency of the *Alnus,* together with the malleability of nutrient cycling under its influence make it an excellent associate for cardamom plantation (Sharma *et al.* 1994, 1995). By comparison with other cash crops, large cardamom is thus low input crop, and nutrient exit through agronomic yield is very minimal, making it an excellent crop for this fragile mountain ecosystem.

Large cardamom is almost a self sufficient system. The post-harvest technology continues to be largely traditional. Farmers have devised indigenous ways of processing cardamom. The capsules are dried in traditional kilns. Fuel-wood is consumed in the ratio of 4:1 for cured cardamom; about 800 kg ha^{-1} of wood are required to cure 200 kg ha^{-1} of finished product. Recently, some institutions have developed improved kilns and gasifiers for curing as well as capsule tail cutting and polishing machines for value addition. Farmers are yet to adopt these technologies.

3.3.5 The future of large cardamom farming

The most worrying factor in large cardamom farming is the decrease in yield per hectare recorded in recent years. The yield of the large cardamom depends upon the age and that most of the plantations (about 10,000 ha) that existed before 1975 are very old and have actually not been producing more than 100 kg ha^{-1} capsules. But the majority of new plantations (about 13,500 ha) are well maintained and produce between 250–350 kg ha^{-1}. New plantations should replace the older ones. Large cardamom starts producing from the 3rd year after planting, and yield declines considerably after the 20th year. Filling the gaps created by withering cardamom bushes and carrying out selective felling of old trees is not enough.

Another cause of decline in large cardamom yield has been infestation mainly by viral diseases viz. "Chirkey" and "Phurkey". This is one of the reasons for production decrease. Uprooting and burning of all the infected plants has been the only possible alternative to control these viral diseases. The Dzongu Golsai variety has been found to be resistant to these diseases. Until now cardamom hybrids have not been developed by any research and development institutions.

In conclusion, cash crop farming holds the key to maintaining the viability of small and marginal farmers in the mountain region. Further expansion of the landholding size is almost impossible. The potentiality for sustainable management of a marginal/fragile mountain land needs serious evaluation.

3.4 Site Characteristics

3.4.1 Study area

3.4.1.1 Location and climate

Three experimental sites selected for the study are located at Kabi (North District), Thekabong (East District) and Sumik (East District) in Sikkim of the Eastern Himalaya. These sites extend within 27° 15′ 05″ to 24° 17′ 36.6″ N latitude and 88° 28″ 6.9″ to 88° 39′ 27.1″ E longitude with an elevation distribution between 1350–1600 m asl. These study sites are more than 80-km distance apart and relates to the major areas of large cardamom cultivation in Sikkim. The study area is in the Indian monsoon region with a temperate climate having the three main seasons: winter (November-February), spring (March-May) and rainy (June-October). Mean monthly maximum temperature ranged from 14.3–23.3°C, mean monthly minimum temperature from 5.4–15.8°C (Fig. 3.2). Mean monthly minimum soil temperature ranged from 6.34–17.61°C and mean monthly maximum soil temperature from 11.48–20.98°C (Fig. 3.2). Total rainfall varied with maximum during monsoon season and minimum in winter season and ranged between 3000–4500 mm per year in the study sites (Fig. 3.3). Relative humidity varied between 80–95% during the rainy season and decreased to about 45% in spring (Fig. 3.3).

Photosynthetically active radiation (PAR) was recorded during 1998–1999 (Fig. 3.3). Mean PAR was highest (655 μ mol m^{-2} sec^{-1}) in April and lowest in September (357 μ mol m^{-2} sec^{-1}).

3.4.1.2 Plantations

All the three experimental sites in Sikkim have several pure stands of *A. nepalensis* tree with understorey large cardamom plantations of different age classes. Large cardamom and *Alnus* trees in a selected stand is of the same age, therefore age designation to the stand refers to the same age for both large cardamom and *Alnus*. The selected *Alnus*-cardamom stands at each of these sites represented plantations of an age sequence of 5-, 10-, 15-, 20-, 30- and 40-years numbering 18 plots altogether. These stands at each of the sites are closely comparable; the structural and functional differences are attributed to the age of the plantations. Soil was acidic (pH 3.8–5.6) and pH varied widely with depth; the variation in pH of surface soils was small between plantations (17%). The soil was sandy loam ranging in horizons from 11–30% clay, 15–40% silt and 34–65% sand in a 1 m profile. The per cent clay and porosity decreased along the soil depth while per cent sand increased down the depth (Table 3.2).

The selection of three sites and stand ages were based on the available information and history of plantations maintained by the cardamom growers. The selection of sites at three different locations was exercised to minimize the heterogeneity and arbitrarity of ecophysiological and microclimatic variations.

3.4.2 Geology

The Sikkim Himalaya is constituted, by the physiographic or geologic terrain's viz. the Tibetan Himalayan Zone, Higher Himalaya, Lower Himalaya etc. It has the world's third highest mountain peak Mt. Kanchandzonga, (8598 m) and other mountain systems.

The Sikkim Himalaya enjoys a wide range of climate, physiography, geology and vegetation that influence the formation of different kind of soil. The soils are in general, acidic in reduction due to heavy rainfall and leaching of bases from surface soil to represent Typhic Hapludolls and Dystric Eutrochrepts largely under the temperate forests. On the other hand, steep slopes (30–50%) with Umbric Dystrochrepts and Cumulic Hapludolls experiences Thermic soil temperature regime and found largely under paddy, maize, cardamom and temperate forests (Mukhopadhyay 1998).

The soil throughout the cardamom based agroforestry stands consists of humus, sandy loam, and dark brown to yellowish brown in colour. Red and yellowish podzolic soils are found in some of the agroforestry stands of higher elevations. The humus layer at the upper soil horizon is due to the deposition of dead organic residue.

3.4.3 Bulk density

The bulk density of the soil horizon (0-15, 15-30 cm) in the age series of *Alnus*-cardamom plantations varied distinctly with higher values at lower depths than upper. The bulk density in the lower depths of all the sites showed lower values indicating the most compact soil in this horizon (Table 3.3). Bulk density varied significantly (P<0.0001) within sites, stand ages and soil depths. Interactions between the sites, stand ages and depths were also significant (P<0.0001). Older plantation stand showed higher bulk density which is an indication of greater soil compactness.

3.5 Stand structure

3.5.1 Diameter at breast height (DBH)

DBH is the one of the important dimension used in factors determining individual tree volume and value. It is generally known to be strongly influenced by stand density and has therefore been investigated in several alder spacing and thinning studies (Bormann 1985; Hibbs *et al.* 1989). DBH is widely used to estimate biomass and production through selective harvest or predictions of established regressions.

Mean DBH of *Alnus* trees in the age series is presented in Table 3.4. DBH of *Alnus* ranged between 8–77 cm in 5- to 40-year stand. Variation within the stand at age 5-year was 8–25 cm, 15-year 18–40 cm and 40-year 37–77 cm. It increased with the increase of age of the plantations.

3.5.2 Tree height

Tree height increased with increase in age of the plantations and basal area (Table 3.5). Mean tree height increased with the advancement of age and ranged between 15 m in 5-year to 35 m in the 40-year stand.

The analysis of tree height within the optimal range or 26 m or below in the *Alnus*-cardamom stand showed that the performance of understorey cardamom was well with greater productivity and agronomic yield. In stands older than 25- to 30-years, height growth and area increase showed considerably above the optimal range of the shade required for better performance of cardamom.

3.5.3 Tree density, parabolic volume and conic surface

Density of trees was highest in 10-year stand and lowest in 40-year stand. Density, parabolic volume and conic surface of *Alnus* trees are presented in Table 3.4. Parabolic volume of the stem is one-half basal area times tree height and conic surface is one-half girth at breast height multiplied by tree height. Parabolic volume of the trees in the age series increased form 70 m^3 ha^{-1} (5-year) to 543 m^3 ha^{-1} (40-year) (Table 3.4). Increase in parabolic volume showed a negative relationship with tree density and in the age series (Fig. 3.5b). Increase in tree density also showed a negative relationship with DBH (Fig. 3.4a). This was because of higher basal area of *Alnus* trees at stands with lower tree density than at higher tree density stands. Increase in DBH showed considerable increase in parabolic volume. Linear regression between parabolic volumes with basal area showed a positive relationship (Fig. 3.5a).

Conic surface of the sampled trees in the age series ranged from 1406 m^2 ha^{-1} (5-year) to 4528 m^2 ha^{-1} (40-year). Conic surface is also related to diameter at breast height and tree height. Parabolic volume and conic surface were comparatively much higher in 30- and 40-year plantation stand than other younger stands (Table 3.4).

3.5.4 Tree basal area

The basal area of the *Alnus* trees on per hectare basis was obtained from the DBH (π $DBH^2/4$) of the individual trees on per hectare basis. Mean basal area of the *Alnus* trees are presented in Table 3.4. Basal area of the individual tree ranged between 0.013 m^2 in 5-year to 0.523 m^2 in 40-year plantation stands. Basal area of a stand largely depends on the tree density and plantation age (Fig. 3.5b).

Stand total basal area on per hectare basis was highly dependent on the basal area of the understorey cardamom. Stand basal area increased from 45 m^2 ha^{-1} (5-year) to 156 m^2 ha^{-1} (15-year) and decreased consistently in the increasing age to a reduced value of 40 m^2 ha^{-1} (40-year). This was due to the small tree density and small number of cardamom bushes in the older stands.

3.5.5 Cardamom bush density, tiller number and basal area

Cardamom bush density increased with increase in plantation age. One possible reason may be gap filling of the cardamom as a management practice. Number of cardamom bush ranged from 10–260x10^2 bush ha^{-1} in 5- to 40-year plantation stands (Table 3.6). This was followed by increase in tiller number in the increasing age groups of plantations. Range of tiller density increased form 5-year (130–160x10^3 tillers ha^{-1}) to a maximum at the 15-year (550–630x10^3 tillers ha^{-1}) and lowest (20–40x10^3 tillers ha^{-1}) in the 40-year stand.

Basal area of cardamom was calculated on tillers per bush and bushes per hectare basis. Basal area of understorey cardamom increased form the 5- (30–37 m^2 ha^{-1}) to 15-year (128–147 m^2 ha^{-1}) and decreased (5–10 m^2 ha^{-1}) in the 40-year stand (Table 3.6). It decreased with increase in age beyond 15 years with corresponding decrease in the number of cardamom tillers and bushes.

3.5.6 Canopy architecture and shade effect

The canopy architecture of a stand is determined by the number, spacing, height and size of the trees. The relationships between leaf area and stand age depend on species, and water and nutrient availability. In plantations, a key issue is the management of canopies to maximize interception of light throughout the rotation. The arrangement of foliage and branches throughout the canopy determines structure. Structure determines penetration of light through the canopy and distribution of micro-environmental factors such as leaf and air temperature, vapour pressure deficit and wind speed.

Canopy cover, canopy volume and canopy depths of different girth classes of *Alnus* are presented in Table 3.5. The range of canopy cover was 14.52 m^2 $tree^{-1}$ (5-year) to 70.85 m^2 $tree^{-1}$ (40-year). Similarly, canopy volume increased consistently from 106 (5-year) to 978 m^3 $tree^{-1}$ (40-year). Due to the highest tree density in the 15-year stand, canopy cover on per hectare basis was highest as compared to other plantations while it was least in older plantations. Canopy depth also increased consistently from 5-year (7.31 m $tree^{-1}$) to 40-year (13.80 m $tree^{-1}$) plantation.

Light interception by the canopy was recorded during full canopy and least canopy stage. Light intensity was recorded in all the stand ages using Lux meter. Light intensity reaching the understorey cardamom was substantially low in the higher tree density stands than in lower tree density stands. In 10-year stand, light intensity received was 86 μmol m^{-2} sec^{-1} while it was 479 μmol m^{-2} sec^{-1} in 40-year stand (Table 3.7).

Appropriate shade conditions and canopy interference of light are the determining factors for humidity and moisture retention, as cardamom requires both of these at high percentage. Cardamom requires diffuse light radiation that minimizes evapotranspiration. High canopy of tall trees beyond 12 m height results in-canopy wind flows which is also disadvantageous for large cardamom. The performance of cardamom was found highly promising within 18–22% of the PAR reaching the understorey cardamom.

3.5.7 Stand tree density management

Two important conclusions are drawn from the traditional stand density management practice. First, stand densities at the time of establishment probably need to be higher than 600–650 trees ha^{-1} to avoid height growth loss due to wide spacing. Second, a reduction of tree density after heavy thinning has been found in stands after 10- to 15-years. This leads to a substantial reduction in tree and stand volume. Densities within 500–600 trees ha^{-1} with subsequent gap filling by cardamom plantation would be appropriate for higher energy conversion efficiency, production efficiency, nitrogen accretion and dynamics of nutrient cycling. This will also ensure sustained yield, nutrient balance, and provide additional income at the end of rotational cycle by harvesting *Alnus* ❖

Table 3.1. Annual cash-benefit analysis and monetary evaluation per hectare (amount in US$ 1 = 46.50 rupees) of large cardamom after three years of plantation in Sikkim. (First year plantation cost =$538 ha^{-1} for planting material and labour; 2^{nd} year =$75.27 ha^{-1} for refilling of gaps and weeding; 3^{rd} year onwards cardamom gives yield and after this weeding, harvest and post harvest cost are cash inputs)

Cost evaluation	Plantation age (year)				
	3	4 – 6	7 – 12	13 – 16	17 – 20
Cost	77.42	120.43	161.29	133.33	124.73
Output	80.65	806.45	1427.73	1532.90	953.76
Benefit/cost ratio	1.04	6.69	8.83	8.49	7.64

The timber and monetary return by the harvest of *Alnus* tree before replanting (20-year rotational cycle) =$12387. This is in addition to cash income from large cardamom yield from 3^{rd} year onwards.

Table 3.2. Soil physical properties under the age series of *Alnus*-cardamom plantation stands. Values are (replicates of three sites) ±SE n=6

Soil depth	Clay (%)	Silt (%)	Sand (%)	Porosity (%)
0–40	22.69±2.98	25.62±4.57	43.93±7.76	69.43±7.08
20–40	25.04±3.55	26.98±3.11	43.64±4.89	68.58±2.87
40–60	21.73±2.88	27.06±4.36	44.57±6.56	66.28±4.68
60–80	18.39±2.39	29.04±4.73	46.35±7.03	62.35±4.91
80–100	17.38±2.51	28.51±5.82	48.52±7.47	58.96±4.65

Table 3.3. Bulk density (g cm^{-3}) at two soil depths at three sites in age series of *Alnus*-cardamom plantation stands.. Values are mean ±SE, n=5

Stand age (year)	Soil depth (cm)	Study sites		
		Thekabong	Sumik	Kabi
5	0-15	0.93±0.04	0.71±0.05	0.64±0.18
	15-30	1.10±0.05	0.77±0.07	0.77±0.28
10	0-15	1.09±0.06	0.63±0.03	0.64±0.08
	15-30	1.12±0.06	0.79±0.03	0.73±0.03
15	0-15	0.68±0.03	0.81±0.09	0.92±0.10
	15-30	1.19±0.06	0.94±0.08	1.02±0.24
20	0-15	0.57±0.02	0.81±0.04	0.62±0.03
	15-30	1.26±0.05	0.97±0.05	0.92±0.03
30	0-15	0.58±0.02	0.64±0.07	0.94±0.06
	15-30	1.14±0.02	1.07±0.03	1.08±0.03
40	0-15	0.61±0.25	0.69±0.03	0.65±0.03
	15-30	1.07±0.49	1.10±0.04	1.09±0.05

ANOVA: Sites $F_{2,72}$ = 25.91, P<0.0001; Stand age $F_{5,72}$ = 4.25, P<0.0001; Depth $F_{1,72}$ = 48.06, P<0.0001; Site x Stand age $F_{10,72}$ = 6.38, P<0.0001; Site x Depth $F_{2,72}$ = 1.25, P<0.0001; Stand age x Depth NS; Site x Stand age x Depth $F_{10,72}$ = 7.45, P<0.0001; LSD (0.05) = 0.05

Table 3.4. Stand tree density, DBH, basal area, parabolic volume and conic surface in the age series of *Alnus*–cardamom plantations. Values are means of three site replicates.

Stand age (year)	Tree density (trees ha^{-1})	DBH (cm)	Basal area (m^2 ha^{-1})	Parabolic volume (m^3 ha^{-1})	Conic surface (m^2 ha^{-1})
5	347	18.05±2.65	8.30±1.45	69.61±18.5	1406±204
10	553	24.00±3.12	12.03±2.11	97.04±18.1	2067±340
15	417	30.14±4.59	19.51±2.89	183.68±53.1	2779±506
20	321	36.13±5.67	22.29±2.36	312.61±66.2	3912±637
30	204	48.80±6.97	23.12±2.68	386.62±60.3	4169±262
40	180	60.25±7.58	30.25±4.16	542.72±170.9	4528±708

Table 3.5. Canopy cover, canopy volume and canopy depth of *Alnus nepalensis* in the age series of *Alnus*-cardamom plantation stands. Values are means ±SE, n=10

Stand age (year)	Tree height (m)	Canopy cover (m^2 $tree^{-1}$)	Canopy volume (m^{-3} $tree^{-1}$)	Canopy depth (m $tree^{-1}$)
5	15.19±1.03	14.52±1.36	106±23	7.31±0.46
10	15.40±1.09	29.88±1.62	269±43	9.06±0.53
15	19.60±1.51	34.89±4.26	414±54	11.86±1.34
20	26.57±4.48	46.08±6.51	570±35	12.37±0.97
30	32.06±4.43	66.00±8.98	854±66	12.95±1.28
40	34.99±1.42	70.85±10.26	978±75	13.80±2.78

Table 3.6. Stand cardamom bush number, tillers density and understorey basal area in the age series of *Alnus*-cardamom plantations. Values are replicates of three sites.

Stand age (year)	Bush number ($\times 10^2$ bush ha^{-1})	Tiller density ($\times 10^3$ tillers ha^{-1})	Basal area ($m^2\ ha^{-1}$)
5	60–70	130–160	30–37
10	130–140	280–330	66–77
15	240–260	560–630	128–147
20	80–100	180–230	42–53
30	70–90	160–200	37–46
40	10–20	20–40	5–10

Table 3.7. Light intensity at the understorey cardamom in the age series of *Alnus*-cardamom plantations. The data were collected between 10.00 to 12.00 hours during sunny days in August 1998, to show the comparative values between the stands.

Stand age (year)	Light intensity under the canopy ($\mu mol\ m^{-2} sec^{-1}$)
5	139.12±43.32
10	86.35±24.65
15	98.96±35.23
20	257.59±65.36
30	478.51±78.69
40	389.68±53.25

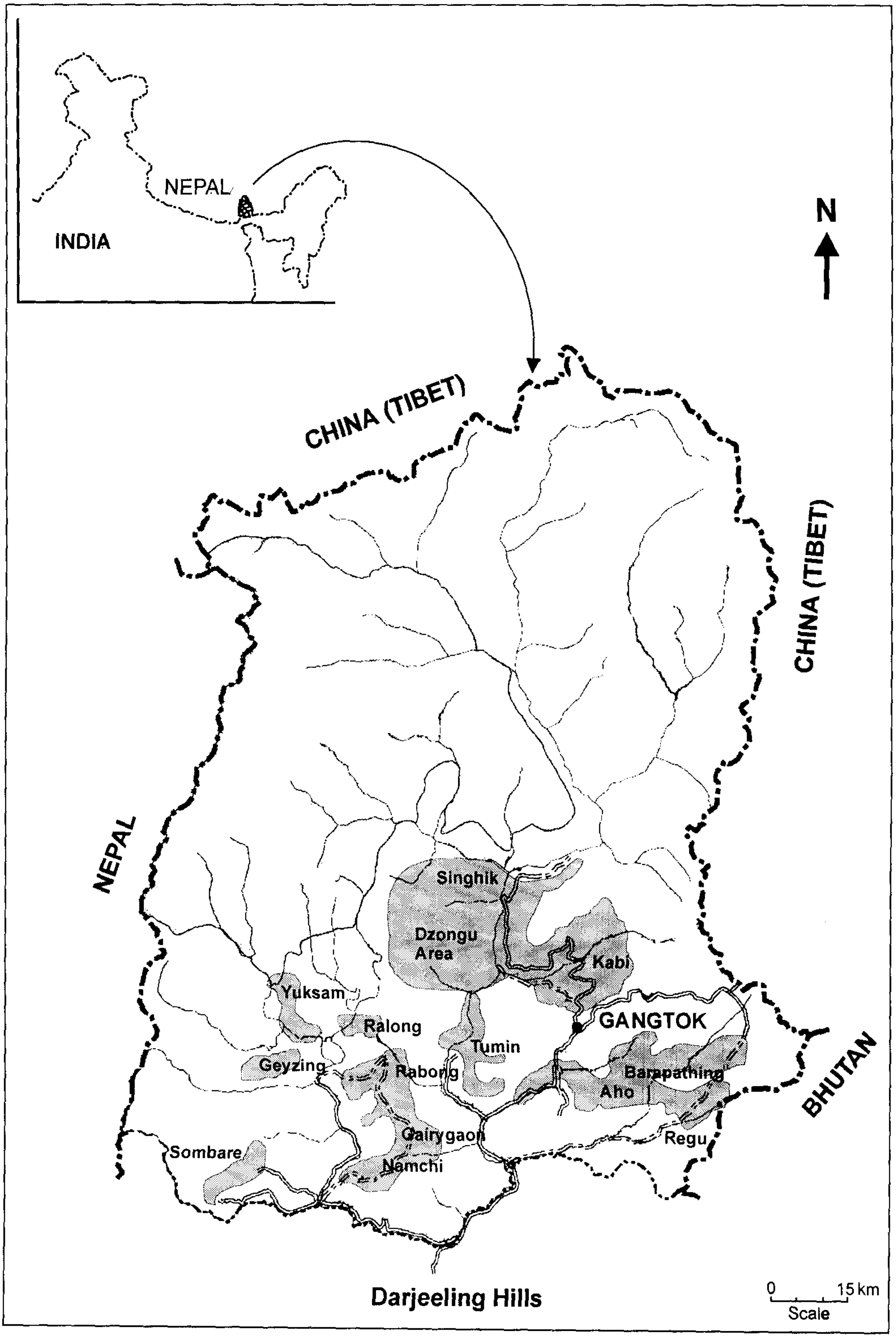
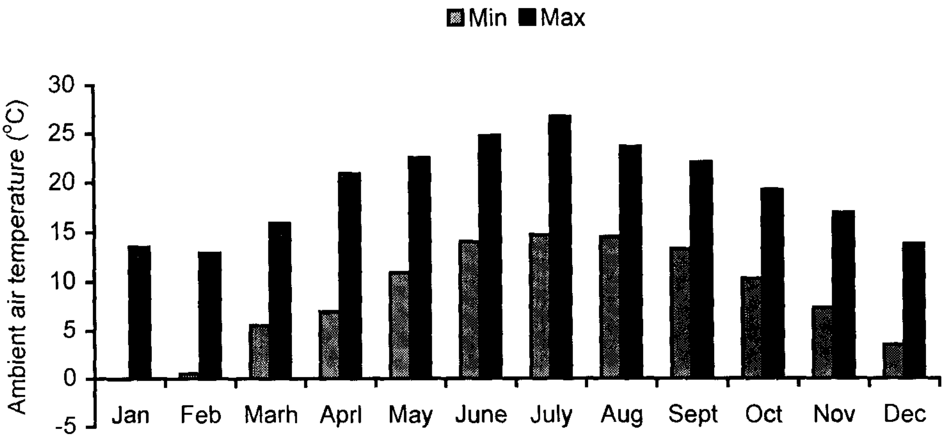


Fig. 3.1. Major cardamom growing areas of Sikkim.



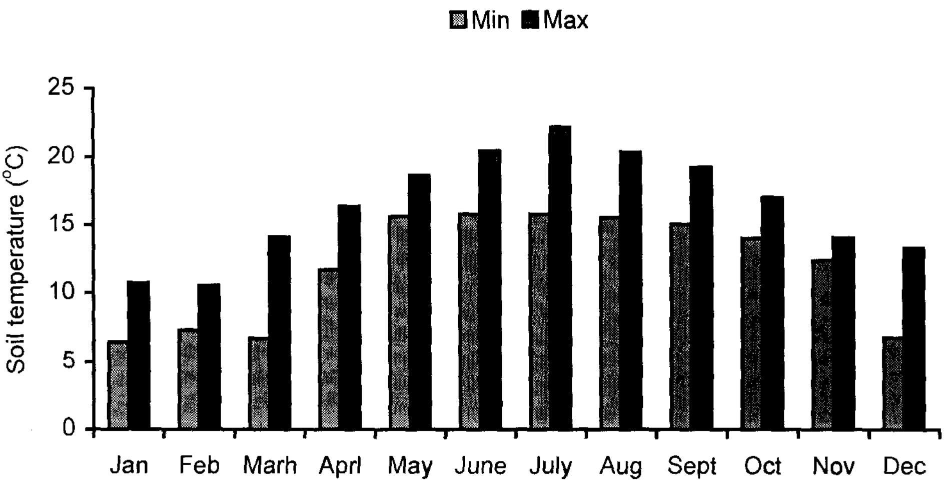


Fig. 3.2. Monthly variation in ambient air and soil temperature at the study sites during 1998.

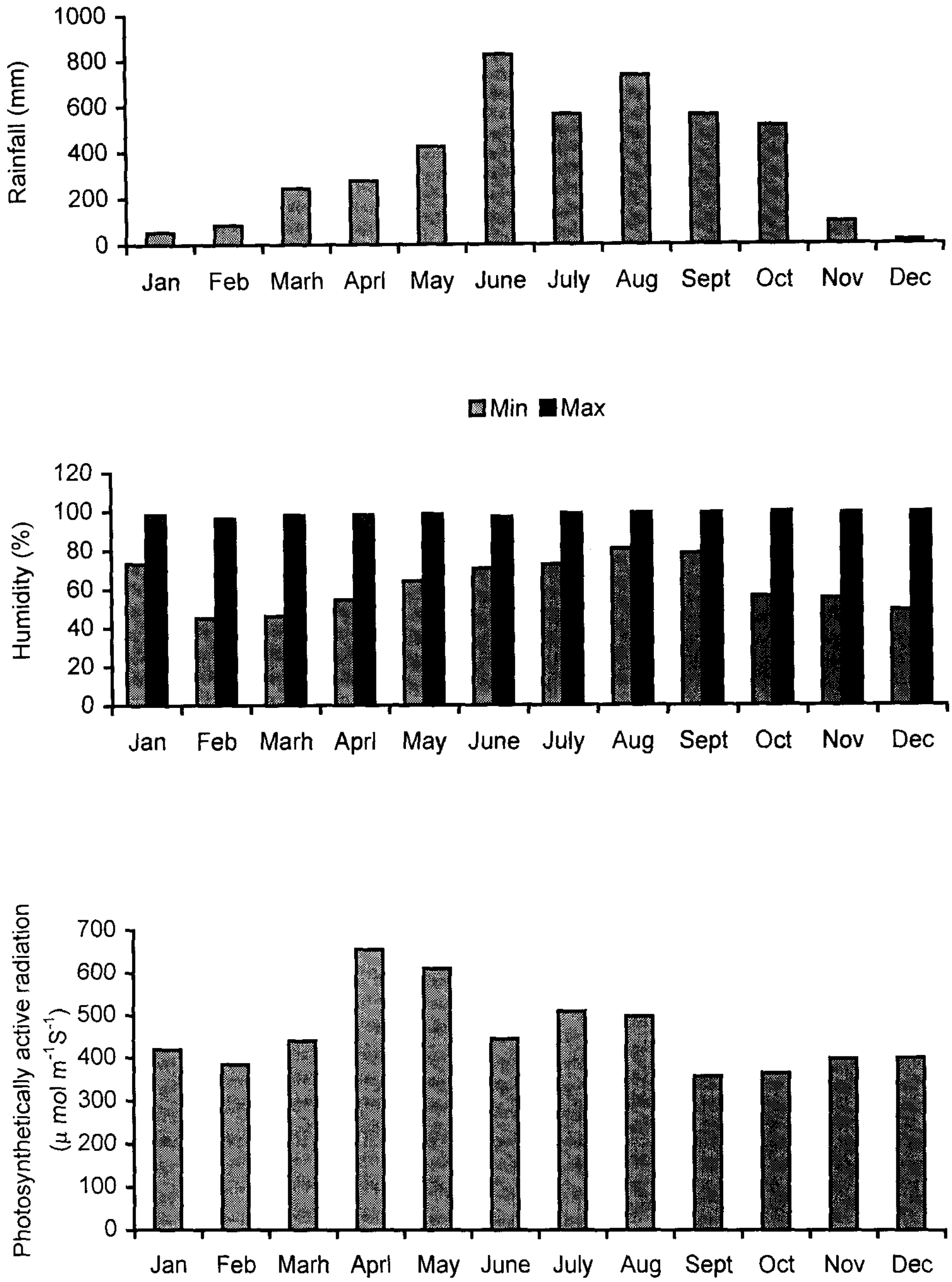


Fig 3.3. Monthly variation in rainfall, relative humidity and photosynthetically active radiation in the study sites during 1998.

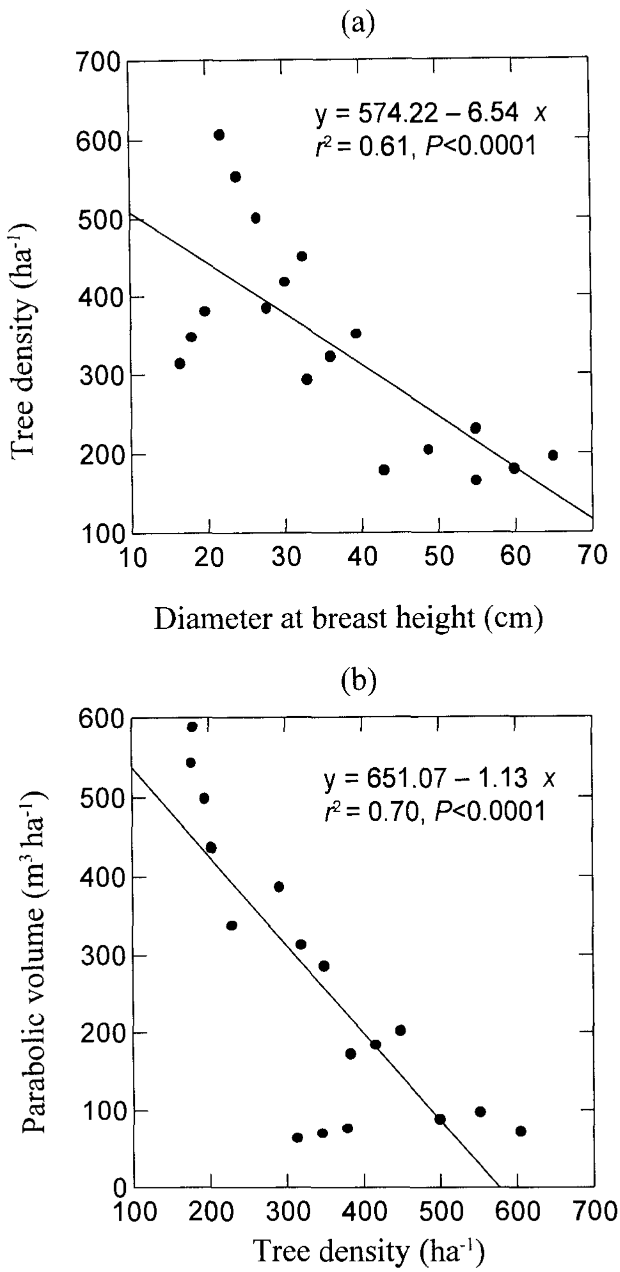


Fig. 3.4. Relationships between (a) tree density and diameter at breast height, and (b) parabolic volume and tree density in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.

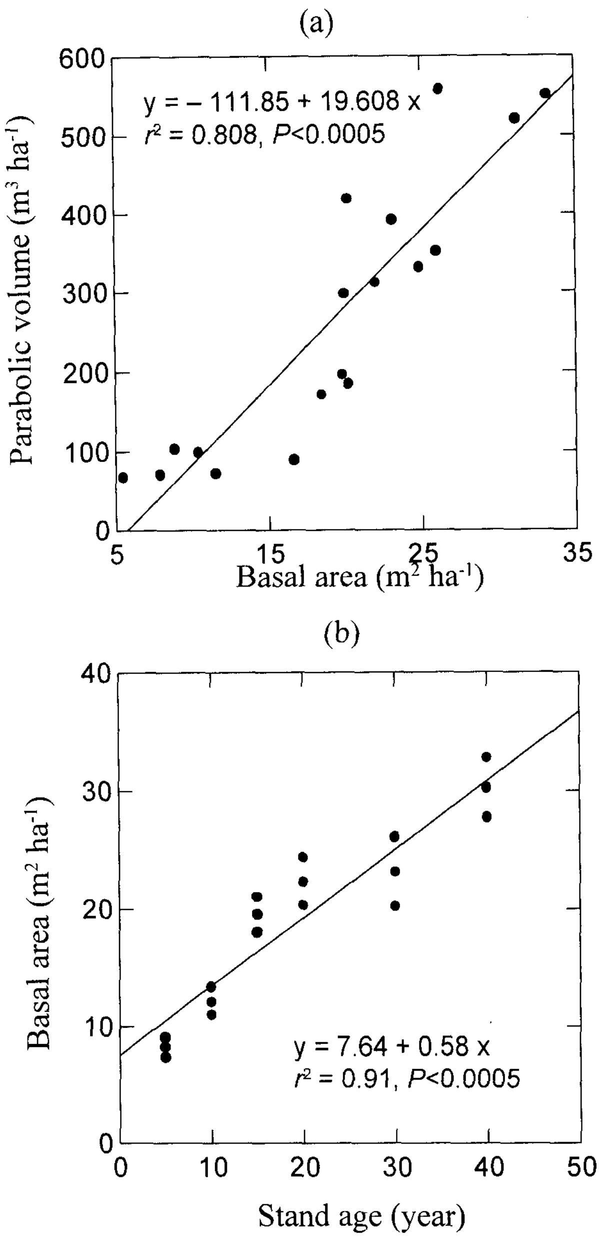


Fig. 3.5. Simple linear regression between (a) parabolic volume and basal area, and (b) basal area and stand age in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.