PRODUCTIVITY, ENERGETICS AND EFFICIENCIES

4.1. Introduction

Intensively managed plantations in temperate and tropical regions have been established largely on such agroclimatic zones where temperature, humidity and rainfall are conducive to higher plantation productivity. Experience in fast growing plantations in temperate regions shows that scientifically based, intensive management practices can increase and sustain productivity (Nambiar 1990, 1996; Beets *et al.* 1994; Sharma *et al.* 1994).

Biomass, productivity and yield in agroforestry systems are related to inputs, outputs and cycling of nutrients consequently affecting soil fertility in the system. The potential role of N_2-fixers as associate species has been realized in the eastern Himalaya which is prevalent in both the cardamom and mandarin agroforestry systems. Studies have been made on site index, biomass and productivity estimates in eastern Nepal by Zomer and Manke (1993). Few reports are available on agroforesrty system functioning from the Central and Sikkim Himalaya (Rahlan *et al.* 1991; Singh *et al.* 1989; Sundriyal *et al.* 1994).

The potential increased productivity of plants growing near N_2-fixing species has been recognized for long. The effects of N_2-fixing trees on interplanted non-N_2-fixing trees have most often been characterized in terms of tree dimensions (Newton *et al.* 1968; Cole and Newton 1986; Heilman 1990). Intensive research over the past few decades has provided a relatively solid foundation for understanding many of the major ecological interactions that occur in mixed stands of N_2-fixing and non-N_2-fixing trees (Binkley 1992). Mixed stands present ecological opportunities for increasing both the total stand growth and growth of the non-N_2-fixing associates (Binkley 1983; Cote and Camire 1987; DeBell *et al.* 1989; Binkley *et al.* 1992a & 1992b). Studies have been carried out on biomass production and energetics in an age series of monocultures of *A. nepalensis* (Sharma and Ambasht 1991). In an 8-year old stand, productivity and yield of understorey large cardamom doubled when planted with N_2-fixing *A. nepalensis* as shade tree compared to non-N_2-fixing tree associates (Sharma *et al.* 1994). However, there is no information available on mixtures of N_2-fixing and non-N_2-fixing stands with respect to their stand age and maturity. *Alnus*-cardamom plantations in the Sikkim Himalaya is a good example for understanding the impact of stand age on performance of mixtures of N_2-fixing and non-N_2-fixing plants.

This chapter examines biomass accumulation, net primary production and energetics in an age sequence of *Alnus*-cardamom plantations. The specific objectives of the study were to determine: (a) component contribution to stand biomass and accumulation pattern; (b) component and total net primary production; (c) differences in component energy values, storage pattern and flow rates; (d) production efficiency and energy conversion efficiency, and (e) relationships between production efficiency, energy conversion efficiency and energy efficiency in N_2-fixation with respect to plantation age function.

4.2. Materials and methods

4.2.1 Biomass, productivity and litter production

Sample plots of 30×40 m were marked at each of the six age series of plantation stands in all the three sites, numbering 18 plots altogether (0.36 ha per each age group totaling to 2.16 ha). Tree diameter increment, litter production, decomposition and agronomic yield estimations were carried out in the above sample plots. Each tree in the sample plots of all age groups was marked and DBH measured in January 1998 and January 2000 (covering two annual cycles). Allometric relationships of tree component biomass on DBH, and belowground biomass on aboveground biomass developed by Sharma and Ambasht (1991) for *A. nepalensis* in the region were used (Table 4.1). The component weight data of each tree in the sample plot were extrapolated using the allometric relationships and then expanded to stand values. Mean annual increment of aboveground components of the individuals in the sample plot was obtained by DBH increment measurements. The belowground biomass of individual trees was calculated using regression equation given by Sharma and Ambasht (1991) and the respective increment in the aboveground biomass (Table 4.1). The net change in the component biomass over one year period yielded annual biomass accumulation and the sum of the different components gave net production of tree strata. Monthly tree litterfall estimations were carried out for a 2-year period (1998-1999) using five litter traps of 1 m² collecting area in each sample plot and pooled to annual values. Floor-litter was randomly sampled in replicates (*n*=5) in an area of 1 m² from each plot in January and extrapolated to stand values. *Alnus* root nodules of five average sized trees from all the 18 plots were recovered for estimation of biomass. Root nodule production was estimated using method given by Sharma and Ambasht (1986b).

In the sample plots of each age group a total number of understorey cardamom bushes were recorded. Average number of tillers per bush was calculated using data of 20 bushes for each plot. Total tillers for the plot was extrapolated using average number of tillers per bush and total number of bush per plot. About 200 tillers from each plot were harvested and measured height, leaf dry weight, pseudo-stem dry weight and bush root/rhizome dry weight for calculating mean values. Tillers that have fruited in the current year are removed after the harvest as a management practice because it does not fruit again. Therefore, the total number of tillers was recorded after the harvest and before the harvest in the next year. The difference between biomass values between this period provided current year leaf, pseudo-stem and root production. The agronomic yield of large cardamom was calculated by counting the tillers that have fruited in the sample area of each stand before the harvest and by multiplying the mean capsule weight per tiller. After the harvest of capsules, the tillers that have fruited in the current year were slashed and estimated the leaf and pseudo-stem fractions and their contribution to floor litter.

4.2.2 Caloric content, energy fixation and efficiencies

Per cent ash content of different plant components was estimated by burning samples in muffle furnace at 550°C for two hours. All energy estimations were made on ash free mass basis. Caloric values of all plant components were estimated using oxygen bomb calorimeter (Lieth 1975). Photosynthetically active radiation (PAR) was recorded by the automatic weather station using dataloger-based Campbell Scientific Inc., USA. Component energy contents of *Alnus* trees and cardamom crop were estimated by taking the product of mean energy value and component dry weight. Energy flow from tree leaf and twig, and cardamom leaf and pseudo-stem to the floor litter was estimated through litterfall and slashed leaf and pseudo-stem and their energy values. The mean energy content of floor litter was calculated by analyzing the caloric content of different litter layers estimated during different intervals of decomposition for all age groups of plantations. The energy contents of the entire representative components such as

Alnus trees, cardamom crop and floor litter of sampled plots were added together in deriving the total stand energy storage. Net energy fixation in trees and understorey cardamom was calculated as the total energy contained in the annual biomass production. Energy efficiency in N_2-fixation by *Alnus* was calculated following Schubert (1982) and Sharma and Ambasht (1988, 1991). N_2-fixation values are presented in Chapter V.

Decomposition studies were carried out by enclosing litter fractions separately in nylon bags and the values of all the fractions were pooled, and annual mass loss on unit area basis was calculated. Details on litter decomposition and energy contents of different components and nutrient and energy release estimated are given in Chapter VI. The sum of the heat release values from different stages of decomposing samples per year presented the total heat release from the floor litter. The energy loss from the root nodules of *Alnus* was estimated using root nodule turnover and decomposition rate conversion factor (Sharma and Ambasht 1986b), and energy values in root nodules.

Energy content of firewood extracted from each plantation was estimated from total dry mass and its energy value. Energy in the agronomic yield was calculated as a product of capsule dry weight and energy value. Energy exit from the system was the sum of energy in extracted firewood and agronomic yield.

Regression equations and graphical presentations were made using Systat 1996. Analysis of variance was carried out for stand net primary productivity and cardamom yield between stand ages, and comparison between means was done by Tukey's pair wise comparison probabilities (Systat 1996).

4.3. Results

4.3.1. Stand structure and litter production

Tree dimensions, cardamom density and basal area are presented in Table 4.2. The DBH range of *Alnus* showed lowest group in the 5-year stand that increased with age to be highest in the 40-year stand. The basal area also increased with age ranging from 8.3 m^2 ha^{-1} in the 5-year stand to 30.3 m^2 ha^{-1} in the 40-year stand. In contrast, the tiller density as well as basal area of large cardamom increased from 5-year to be highest in 15-year and then decreased to the lowest value in the 40-year stand (Table 4.2).

Average annual litterfall and slashed cardamom tiller ranged from 4.1 t ha^{-1} (40-year stand) to 10.3 t ha^{-1} (15-year stand). Plantation floor-litter increased from the 5-year stand to a peak at age 15-year (35 t ha^{-1}), and then decreased to the lowest value in the 40-year stand (Table 4.2). The ratio of litter production to floor-litter was higher in the youngest and oldest stands, and lowest in the 15-year stand (0.24).

Litter production occurred throughout the year with a marked seasonal distribution (Fig. 4.1). Quantity of the litter production was highly dependent on age of the plantation stands. About 66% of annual litter production was recorded between a four-month period (September-December). Seasonal distribution of litter production showed little difference between year 1 and year 2, or between plantation stands.

4.3.2. Standing biomass and net primary productivity

Total stand biomass in the age sequence of *Alnus*-cardamom plantations increased from 41 t ha^{-1} in the 5-year stand to 132 t ha^{-1} in the 40-year stand. A range from 48–62% of the live biomass of the tree stratum was contributed by bole. Per cent contribution of branch biomass to total tree biomass remained nearly the same in all the plantation stands while the bole biomass contribution increased conspicuously with plantation age. The relationships between the DBH of the increasing age series and their respective component biomass of *Alnus* and relationships between cardamom root biomass and shoot biomass were highly significant (Fig. 4.2 & 4.3)

Biomass contribution of *Alnus* to stand values ranged from 65–97%, whose contribution was higher in the 5-year stand that decreased to the lowest value at the 15-year stand and then further increased to be highest at the 40-year stand (Table 4.3). Stand aboveground biomass increased with stand age while the belowground biomass peaked in the 15-year stand that was mainly attributed to cardamom contribution. The contribution of belowground biomass ranged from 17–38% of the stand total. The standing biomass of trees showed a negative relationship with the stand tree density, while it was positive with the tree basal area. However, in the case of cardamom biomass positive relationships were obtained both with cardamom bush density and basal area (Fig. 4.4).

The net primary production rates of the age sequence of *Alnus*-cardamom plantations ranged from 7–22 t ha^{-1} $year^{-1}$, increasing to a peak at the 15-year stand, and then declining to the lowest value in the 40-year stand (Table 4.4). Analysis of variance for stand net primary productivity showed significant variation between stand age ($F_{5,12}$=25, $P<0.0001$). Tukey's pair wise comparison probabilities showed significant variation between– 5-year with 15-year (P<0.02); 10-year with 20-year ($P<0.06$), 30-year and 40-year stands ($P<0.0001$) and 20-year and 30-year with 40-year stand ($P<0.004$). Contribution of aboveground productivity hovered around 65–69% in younger stands and increased to a highest value of 88% in the 40-year stand. Contribution of cardamom net primary production to the stand value ranged from 12% (40-year stand) to 44% (15-year stand). The agronomic yield of cardamom increased from 110 kg ha^{-1} $year^{-1}$ in the 5-year stand with a peak value of 360 kg ha^{-1} $year^{-1}$ in the 20-year stand which sharply declined in older stands to a minimum value of 40 kg ha^{-1} $year^{-1}$ in the 40-year stand. Analysis of variance for agronomic yield of large cardamom varied significantly between stand age ($F_{5,12}$=456, P<0.0001). Tukey's pair wise comparison probabilities were significant between all combinations of stand age (P<0.0001).

Biomasss accumulation ratio (BAR, Biomass/net primary production) was calculated for the stand total and separately for the shade tree in the age sequence of *Alnus*-cardamom plantations (Fig. 4.5). The BAR of the stand and the *Alnus* tree was lowest in the 5-year stand and increased with stand age to be highest in the 40-year stand which was about 7-times greater than the 5-year stand. However, in the case of understorey cardamom, it was lowest (1.68) in the 5-year stand and increased to 3.54 in the 15-year stand that remained nearly the same thereafter in older stands. The BAR of the stand total and *Alnus* tree showed strong positive relationships with stand age, however in understorey cardamom it was significantly positive but feeble (r^2=0.45, P<0.05).

The net primary production per unit weight of leaf is the production efficiency, and it ranged from 2.97–8.38 t t leaf^{-1} year^{-1} in cardamom and 3.63–6.27 t t leaf^{-1} year^{-1} in *Alnus* tree. It was highest in the 5-year stand and lowest in the 40-year stand. It showed highly negative relationships with plantation age for stand total and for both *Alnus* tree and understorey cardamom (Fig. 4.6). The efficiency curve tended to flatten with plantation age especially in the case of *Alnus* tree.

Compartment model showing the distribution of biomass and net primary production in the age series of *Alnus*-cardamom plantation stands are presented in Figure 4.7a, b & c. Values in the compartments are biomass and arrows show net flow rate. The differences of the values on the arrows of either side of a compartment give the component net production. A comparative account of the six stand ages of plantations showed high biomass build up with stand age maturity especially of perennial parts like bole, branch and belowground parts. The biomass build up in the cardamom recorded until 15 years of plantation age and then declined with increase in stand age.

4.3.3. Energy value, energetics and efficiencies

Energy and ash concentrations of different plant components of *Alnus,* cardamom and floor-litter are given in Table 4.5. Ash ranged from 2.01–11.59% in *Alnus* and 3.72–12.13% in cardamom components. It was highest in root nodules of *Alnus* tree while underground parts and capsule in the case of cardamom. Floor-litter showed the highest (14.52%) ash concentration (Table 4.5). The energy value of component parts of the *Alnus* trees ranged from 17.54–21.25 kJ g^{-1} and 15.02–19.93 kJ g^{-1} in cardamom (Table 4.5). The mean energy value of floor-litter, calculated using the values of different stages of decomposition, was 15.06 kJ g^{-1}.

Compartment model showing the details of energy storage net energy flow and heat sink through the stand floor due to decomposition in the age series of plantation stands are presented in Figure 4.8a, b & c. Values in the compartments are energy storage and annual net energy flow rate is indicated by arrows.

The net energy contents in the standing biomass of *Alnus*-cardamom plantations followed the biomass build up trend. It increased from 774×10^6 kJ ha^{-1} $year^{-1}$ in the 5-year stand to 2414×10^6 kJ ha^{-1} $year^{-1}$ in the 40-year stand (Table 4.6). Per cent energy content in tree biomass ranged from 79–98 whereas cardamom contributed 2–21% in the age series of plantations. Energy contribution by cardamom decreased sharply after 15-year plantations.

Component wise transfer of energy to the stand floor through litter production is presented in Table 4.8. Contribution of litter by *Alnus* ranged between 73×10^6 kJ ha^{-1} $year^{-1}$ (5-year) to 128×10^6 kJ ha^{-1} $year^{-1}$ (15-year). Similarly, contribution of litter production by cardamom ranged between 6.29×10^6 kJ ha^{-1} $year^{-1}$ (40-year, lowest) to 66.94×10^6 kJ ha^{-1} $year^{-1}$ (15-year, highest). The 15-year stand added significant amount of energy to the stand.

Net annual energy fixation was lowest (154×10^6 kJ ha^{-1} $year^{-1}$) in the 40-year stand and highest (444×10^6 kJ ha^{-1} $year^{-1}$) in the 15-year stand (Table 4.7). Annual energy fixation in 15-year stand was 1.4 times that of 5-year stand and 2.9 times that of the 40-year stands. Energy allocation in agronomic yield of the large cardamom was highest (7.05×10^6 kJ ha^{-1} $year^{-1}$) in 20-year stand which was 3.2 times greater than that of 5-year stand and 9 times that of 40-year stand. Allocation of stand annual energy fixation to shade tree and cardamom was respectively, 72% and 28% in 5-year stand, 62% and 38% in 15-year stand, and 90% and 10% in 40-year stand. Energy storage was lowest in 5-year stand and increased with plantation age to be 2.5 times greater in 40-year stand (Table 4.9).

Component allocation of net energy fixation in the tree layer of the 5-year stand was more than 15-year stand in the case of bole, branch and root while the reverse was recorded for leaf and twig, root nodule and catkins. In the case of cardamom all the components such as leaf, pseudo-stem, capsule and root/rhizome showed higher net energy allocation in the 15-year stand compared to the 5-year stand while the least allocation was recorded in all the components of cardamom of 40-year stand. Heat sink from the floor-litter and energy exit in terms of firewood and capsule are given in Table 4.9 and Fig. 4.8a, b & c. Heat sink was highest in the 15-year stand and decreased in the order 15>20>10>30>5>40 year stand. Energy exit from the system in the case of 5-year stand was 2.2×10^{6} kJ ha^{-1} $year^{-1}$ which increased to the greatest value in 10- and 15-year stands and then declined in the order 10>15>40>30>20>5 year stand.

Net ecosystem energy increment was highest in the 5-year stand (149×10^{6} kJ ha^{-1} $year^{-1}$) which decreased with plantation age to a minimum value of 10×10^6 kJ ha^{-1} $year^{-1}$ in the 40-year stand. However, the energy accumulation ratio (energy storage/energy fixation) was lowest in the 5-year stand and increased with plantation age to the greatest value at the 40-year stand (Table 4.9). Net ecosystem energy increment showed strong negative relationship with stand age while the energy accumulation ratio was positively related with stand age (Fig. 4.9). The best fit of net ecosystem energy increment and energy accumulation ratio curves was obtained using the natural logarithmic form of plantation age.

Energy conversion efficiency (ECE) at the autotrophic level is the ratio of energy captured by vegetation to the photosynthetically active radiation reaching an area over a period of time expressed as percentage. The ECE increased from 5-year stand (2.72%) to peak at the 15-year stand (3.76%) thereafter decreased with stand age to a minimum of 1.3% in the 40-year stand. Relationship between ECE with stand age is strongly negative in all the three cases such as *Alnus* tree, cardamom and stand total (Fig. 4.10a, b & c). In all these three situations, curves showed slight increase in the younger stands and then sharply declined with older stands. The production efficiency showed a positive relationship with energy conversion efficiency (Fig. 4.10d). Both production and energy conversion efficiencies were high in the younger stands and decreased with stand age to the lowest value at 40-year stand.

Energy utilized per kg N_2 fixed was 16×10^4 kJ in the 5-year stand which slightly decreased with stand age and remained almost similar throughout with the value of 12×10^4 kJ in the 40-year stand. Energy utilized per kg N_2 fixed dropped sharply from 5-year to 10-year stand and then more slowly thereafter. It showed negative relationship with plantation age that was converted into natural logarithmic form (Fig. 4.11). Energy efficiency in N_2-fixation was lowest (64 g N_2 fixed 10^4 kJ^{-1} energy) in the 5-year stand and increased to be highest (84 g N_2 fixed 10^4 kJ^{-1} energy) in the 40-year stand. Efficiency in N_2-fixation between 10- to 30-year stands remained almost similar. Energy efficiency in N_2-fixation showed a significant negative relationship with production efficiency (Fig. 4.11), indicating greater energy efficiency in N_2-fixation in the 40-year stand when production efficiency was the lowest.

4.4. Discussion

The annual variation of tree leaf litter and cardamom litter production within each plantation age during the two-year study period was low. The temporal distribution of tree leaf-litter production was similar in all the six age groups of stands showing a regular pattern. Sharma *et al.* (1997a) reported higher litter production under the influence of N_2-fixing *Alnus* tree in cardamom plantations compared to non-N_2-fixing mix tree species. Tarrant *et al.* (1969) and Binkley (1992) also found much more litter production in mix stands with N_2-fixing associates than in stands containing only non-N_2-fixing trees. Bormann and DeBell (1981) reported a floor-litter value as high as 39 t ha^{-1} in a 40-year *A. rubra* stand, and indicated a possibility of reaching equilibrium at 25-year of age. However, the equilibrium of litter accumulation could not be firmly established in the present study due to large cardamom crop management practice.

The stand total biomass, tiller number, basal area and biomass of cardamom crop were much higher under the influence of *Alnus* (Sharma *et al.* 1994). Binkley *et al.* (1992a) have also reported that at a low fertility site in USA biomass of *Alnus*-conifer stands exceeded by 69% to that of pure conifer stands. The total biomass in the age sequence of pure *A. nepalensis* plantations increased from 106 t ha^{-1} in the 7-year stand to 606 t ha^{-1} in 56-year stand (Sharma and Ambasht 1991). In the age sequence of mixture of *Alnus*-cardamom plantations, the biomass accumulation trend similar to that of above study was recorded although of a lower magnitude. The *Alnus* tree associate mainly influenced it. The biomass accumulation ratio is used for categorizing the production conditions of forests/plantations (Whittaker and Woodwell 1969). It expresses the amount of biomass accumulated per unit of net production. The change in biomass accumulation ratio is caused by the differences in site characteristics and wood increment rates as affected by environmental conditions and age of the trees. The biomass accumulation ratio ranged between 2.5–18.0 in the age sequence of *Alnus*-cardamom plantations. Smith (1977) has also reported low average rates of 2.86 biomass accumulation ratio in immature 8–10-year-old A. *rubra* stand, consistent with report made by Sharma and Ambasht (1991) and in the present study.

Sharma and Ambasht (1991) reported net annual production rates of 13–25 t ha^{-1} $year^{-1}$ in the age sequence of pure *Alnus* plantations which decreased with age closely matching the trend in the total net primary productivity of the *Alnus* associates in the *Alnus*-cardamom plantations ranging form 6.5–12.6 t ha^{-1} $year^{-1}$. Immature stands often have net primary production rates more than twice as great as mature stands (Johnson and Risser 1974). This is also true in the present study, which showed that the net production rate in the 40-year plantations was about 33% of the 15-year stand. Rodin and Bazilevich (1967) have given a broad range of 3.6–20 t ha^{-1} $year^{-1}$ net productivity for temperate deciduous forest and the present study values were within this range. Productivity of *Alnus* was almost similar up to 15-year stand and then declined with age. However under the influence of *Alnus*, cardamom productivity doubled in 15-year stand compared to the 5-year stand, thereafter it decreased sharply with stand age to a lowest value in the 40-year stand. Performance of cardamom in the association of N_2-fixing *Alnus* remained beneficial until 20 years.

Net annual energy fixation was reported highest in a young stand and declined sharply with plantation age on pure *A. nepalensis* in the region (Sharma and Ambasht 1991). In the present study annual energy fixation and flow rates increased from 5-year stand to a peak at the 15-year stand and then sharply declined. This clearly indicated that energy flows and fixation were optimum for both *Alnus* and cardamom up to the 15-year stand age. The production efficiency and energy conversion efficiencies of the age sequence of *Alnus*-cardamom plantations showed a significant positive relationship where the younger stands performed more efficiently compared to mature stands. The production efficiency of the plantation was highest in the 5-year old stand that decreased with advancing age having similar trend in both *Alnus* as well as cardamom components. The energy fixation efficiency of cardamom decreased with advancing age which remained fairly high up to 20-year old stand supporting the system efficiency until this age. The energy efficiency of stands and separately for *Alnus* and cardamom components was highest in the youngest stand and decreased with advancing plantation age. The energy conversion efficiency of cardamom increased from the 5-year stand up to the 15-year stand and then decreased to the lowest efficiency in the 40-year stand. Energy accumulation ratio of *Alnus* increased with stand age almost reaching more than 5 times in 40-year stand compared to 5-year stand, whereas it was almost similar after 15-year age in the case of cardamom. The relationships of energy efficiency in N_2-fixation with production efficiency of the *Alnus*-cardamom plantations showed inverse function. Younger stands with higher production efficiency showed least efficiency in N_2-fixation. However, as the stands matured the production efficiency decreased and the system suddenly switched to increased energy efficiency in the N_2-fixation. The inverse relationships of production efficiency, energy conversion efficiency and energy utilized in N_2-fixation against stand age, and positive relationship between production efficiency and energy conversion efficiency suggest that younger plantations function as the most productive system, while the intermediate and mature plantations relatively less and least productive, respectively. Performance of large cardamom under the influence of N_2-fixing *Alnus* in an age sequence of plantation with regards to net primary productivity, agronomic yield, net energy fixation rates, production efficiency, energy conversion efficiency and energy efficiency in N_2-fixation suggest the optimal rotational 20 years age. Sharma *et al.* (1994) suggested *Alnus* as an excellent associate with cardamom promoting higher performance compared to non-N_2-fixing mix tree associates. This study reveals that the *Alnus*-cardamom plantation system could be sustainable by adopting rotational cycle of 20 years ❖

Table 4.1. Logarithmic regressions relating component biomass with the function of tree diameter at breast height, and beloewground biomass with aboveground biomass, of the harvested sample alder trees ('E' is the antilog of the standard error of the logarithm of the y-value and 'r' is the coefficients of correlation).

Regression equation	d.f	r^{Ψ}	E
$\text{Log}_{10}\,\text{TLDW} = 2.963 + 0.628\,\log_{10}\text{DBH}$	21	0.977	1.011
$\text{Log}_{10}\,\text{CDW} = 1.348 + 1.281\,\log_{10}\text{DBH}$	20	0.998	1.005
$\text{Log}_{10}\,\text{BrDW} = 1.455 + 2.216\,\log_{10}\text{DBH}$	21	0.993	1.021
$\text{Log}_{10}\,\text{BDW} = 1.532 + 2.461\,\log_{10}\text{DBH}$	21	0.977	1.016
$\text{Log}_{10}\,\text{BgDW} = 0.916 + 0.720\,\log_{10}\text{AgDW}$	21	0.992	1.018

DBH = diameter at breast height (range, 18–80 cm); TLDW = twig and leaf dry wt. (g); CDW = catkin dry wt. (g); BeDW = aboveground dry wt. (g); BDW = bole dry wt. (g); BrDW = branch dry wt. (g); AgDW = aboveground dry wt. (g); and BgDW = belowground dry wt. (g). $^{\Psi}$ Significant at $P < 0.001$.

(After Sharma and Ambasht 1991)

Table 4.2. Tree dimensions, number of understorey cardamom tillers and bushes, basal area, litter production and floor-litter in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.

Parameters	Plantation stands (year)					
	5	10	15	20	30	40
Tree (*Alnus nepalensis*)						
Density (trees ha^{-1})	347 ±20	553 ±65	417 ±17	321 ±33	204 ±29	180 ±9
DBH range (cm)	8-25	13-35	18-40	23-47	34-67	37-77
Height (m)	15.19 ±1.02	15.40 ±1.09	19.60 ±1.51	26.57 ±4.48	32.06 ±4.43	34.99 ±1.42
Basal area (m^2 ha^{-1})	8.3 ±1.43	12.03 ±2.00	19.51 ±3.43	22.29 ±3.55	23.12 ±3.75	30.25 ±7.45
Cardamom (*Amomum subulatum*)						
Bush (number ha^{-1})	6786 ±655	13484 ±3100	25316 ±1706	8797 ±1733	7962 ±2467	1733 ±186
Tiller density (x 10^4 tillers ha^{-1})	15.61 ±1.51	31.01 ±7.13	58.23 ±3.92	20.23 ±3.99	18.31 ±5.67	3.99 ±0.43
Basal area (m^2 ha^{-1})	36.52 ±3.51	72.57 ±8.10	136.25 ±20.31	47.35 ±6.75	42.85 ±7.89	9.33 ±2.11
Stand basal area (m^2 ha^{-1})	44.82 ±0.16	84.60 ±4.60	155.76 ±5.95	69.64 ±3.73	65.97 ±3.82	39.58 ±7.55
Litter production (t ha^{-1} $year^{-1}$)	5.88 ±0.58	8.24 ±1.72	10.25 ±0.46	7.11 ±3.77	6.62 ±1.46	4.08 ±0.54
Floor-litter (t ha^{-1})	18.51 ±0.25	23.16 ±2.06	34.91 ±1.24	28.05 ±1.44	24.27 ±0.58	14.67 ±1.04
Litter production: floor litter	0.32	0.36	0.29	0.28	0.27	0.27

Table 4.3. Biomass (t ha^{-1}) allocation in tree and cardamom components, and stand values in the age series of *Alnus*-cardamom plantation stands. Values in the parentheses are per cent contribution. Values are means of three site replicates.

Plant components	Stand age (year)					
	5	10	15	20	30	40
Tree						
Leaf and twig	1.84 ±0.06	2.91 ±0.12	2.64 ±0.07	2.45 ±0.29	1.82 ±0.16	1.78 ±0.02
Catkin	0.30 ±0.04	0.45 ±0.07	0.50 ±0.07	0.55 ±0.08	0.53 ±0.07	0.53 ±0.09
Branch	6.84 ±0.67	8.71 ±1.14	13.64 ±3.35	17.61 ±3.23	18.94 ±3.36	25.91 ±6.94
Bole	15.77 ±2.93	20.13 ±1.76	35.07 9.97	48.08 ±8.85	54.07 ±10.16	80.47 ±23.64
Root and root nodule	7.96 ±1.19	8.09 ±0.68	12.76 ±4.32	17.93 ±2.87	18.61 ±2.73	20.67 ±4.55
Total	32.71	40.29	64.61	86.62	93.97	129.36
Cardamom						
Cardamom ieaf	0.62 ±0.06	1.24 ±0.29	2.33 ±0.95	1.06 ±0.16	1.20 ±0.23	0.29 ±0.09
Pseudo-stem	1.87 ±0.02	3.72 ±0.86	6.94 ±2.88	3.18 ±0.31	2.19 ±0.68	0.88 ±0.29
Root/rhizome	6.79 ±0.66	13.48 ±0.31	25.30 ±5.13	10.79 ±0.79	7.96 ±2.47	1.73 ±0.19
Total	8.72	18.44	34.57	15.03	11.35	2.90
Aboveground biomass	26.68 (64.39)	37.16 (63.27)	61.12 (61.63)	72.93 (71.75)	78.75 (74.77)	109.86 (83.06)
Belowground biomass	14.75 (35.60)	21.57 (36.73)	38.06 (38.37)	28.72 (28.25)	26.57 (25.23)	22.40 (16.94)
Stand biomass	41.43	58.73	99.18	101.65	105.32	132.26

Table 4.4. Component wise estimates of net primary productivity of *Alnus* tree and understorey cardamom (t ha^{-1} year^{-1}) in the age series of *Alnus*-cardamom plantation stands. Values in the parenthesis are percent net contribution. Values are means of three site replicates.

Plant components	Stand age (year)					
	5	10	15	20	30	40
Tree						
Leaf & twig	3.19 ±0.06	4.07 ±0.12	5.63 ±0.07	4.77 ±0.29	4.42 ±0.16	3.17 ±0.02
Catkin	0.30 ±0.04	0.45 ±0.07	0.50 ±0.07	0.55 ±0.08	0.53 ±0.07	0.52 ±0.09
Branch	1.82 ±0.46	1.66 ±0.22	1.25 ±0.22	1.17 ±0.23	1.13 ±0.24	0.75 ±0.01
Bole	3.47 ±0.03	3.34 ±0.89	2.88 ±0.16	2.23 ±0.57	1.78 ±0.22	1.56 ±0.51
Root and root nodule	2.75 ±0.57	2.73 ±0.92	2.35 ±0.28	1.70 ±0.09	1.35 ±0.08	0.47 ±0.05
Total	11.53	12.25	12.61	10.42	9.21	6.47
Cardamom						
Cardamom leaf	0.60 ±0.29	0.93 ±0.40	1.03 ±0.15	0.45 ±0.91	0.42 ±0.71	0.10 ±0.02
Pseudo-stem	1.79 ±0.42	2.79 ±0.43	3.09 ±1.29	1.34 ±0.35	1.25 ±0.35	0.29 ±0.05
Capsule	0.11 ±0.02	0.23 ±0.03	0.31 ±0.04	0.36 ±0.02	0.18 ±0.11	0.04 ±0.01
Root/rhizome	2.70 ±0.39	3.37 ±1.03	5.33 ±1.89	2.19 ±0.43	2.01 ±0.60	0.43 ±0.05
Total	5.20	7.32	9.77	4.30	3.85	0.86
Aboveground productivity	11.28 (67.42)	13.47 (68.83)	14.69 (65.58)	10.87 (73.84)	9.70 (74.27)	6.43 (87.48)
Belowground productivity	5.45 (32.58)	6.10 (31.17)	7.68 (32.28)	3.85 (26.15)	3.36 (25.72)	0.90 (12.24)
Stand net primary productivity	16.73	19.57	22.38	14.72	13.06	7.33

Table 4.5. Energy and ash content of different plant components of *Alnus* tree, cardamom crop and floor litter. Values are mean ±SE, $n = 6$

Plant components	Energy (kJ g^{-1})	Ash (%)
Tree		
Leaf	20.92±0.82	2.42±0.59
Twig	20.44±0.08	2.70±0.67
Catkin	20.18±0.35	2.43±0.81
Branch	19.76±0.66	2.82±0.91
Bole	17.84±0.02	2.01±0.34
Root	17.54±0.19	5.21±0.71
Root nodule*	21.25±0.86	11.59±2.10
Cardamom		
Leaf	19.93±0.22	5.62±2.10
Pseudo-stem	15.02±0.07	3.72±0.11
Rhizome	18.06±0.76	10.92±0.82
Root	18.84±0.36	11.12±0.90
Capsule	17.96±0.58	12.13±0.40
Floor litter[£]	15.06±0.98	14.52±0.60

£ Analyzed from different stages of decomposition

* Analyzed from different stages of development

Table 4.6. Energy content (x 10^6 kJ ha^{-1}) of different plant components of trees and cardamom in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.

Plant components	Stand age (year)					
	5	10	15	20	30	40
Tree						
Leaf and twig	39.07 ±5.37	59.99 ±11.15	54.59 ±6.21	50.06 ±5.86	37.70 ±5.41	36.73 ±4.08
Catkin	6.09 ±0.79	9.04 ±1.39	10.13 ±1.45	11.08 ±1.58	10.72 ±4.42	10.61 ±1.89
Branch	135.16 ±13.04	172.11 ±22.53	269.53 ±66.19	347.97 ±63.82	374.25 ±66.39	511.98 ±137.13
Bole	281.34 ±52.27	359.12 ±31.39	625.65 ±177.86	857.75 ±157.88	964.61 189.82	1435.58 ±421.74
Root	139.62 ±20.87	142.00 ±11.99	223.81 ±75.77	314.49 ±50.34	326.42 ±47.88	362.55 ±79.81
Root nodule	7.17 ±1.11	15.65 ±2.83	17.21 ±3.21	13.07 ±2.38	7.12 ±1.38	5.78 ±2.11
Total	608.5 ±72.4	757.90 ±49.70	1200.9 ±340.1	1594.9 ±286.3	1720.8 ±319.8	2363.23 ±615.9
Cardamom						
Cardamom leaf	12.42 ±1.13	24.71 ±5.45	46.44 ±17.85	21.13 ±3.01	24.81 ±4.32	5.84 ±1.86
Pseudo-stem	28.09 0.30	55.87 ±12. 91	104.84 ±43.25	47.26 ±4.67	32.89 ±10.25	13.22 ±4.49
Root/rhizome	122.63 ±11.91	243.45 ±5.60	456.92 ±92.65	194.87 ±14.26	143.76 ±44.61	31.24 ±3.36
Capsule	2.19 ±0.27	4.47 ±0.59	6.02 ±0.74	7.05 ±0.34	3.40 ±0.20	0.78 ±0.04
Total	165.33 ±39.29	328.50 ±75.76	614.22 ±101.50	270.81 ±57.59	204.86 ±50.57	51.08 ±19.79
Net stand energy content	774	1086	1815	1866	1926	2414

Table 4.7. Component wise net energy fixation (x 10^6 kJ ha^{-1} $year^{-1}$) of different plant components of trees and undersotrey cardamom in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.

Plant components	Stand age (year)					
	5	10	15	20	30	40
Tree						
Leaf and twig	66.73 ±1.24	85.14 ±2.48	117.78 ±1.44	99.78 ±5.99	92.47 ±3.31	66.32 ±0.41
Catkin	6.09 ±8.07	9.04 ±1.41	10.13 ±1.41	11.08 ±1.61	10.72 ±1.42	10.61 ±1.82
Branch	35.96 ±9.09	32.80 ±4.34	24.70 ±4.35	23.12 ±4.54	22.33 ±4.74	14.78 ±0.20
Bole	61.90 ±0.54	59.59 ±15.87	51.38 ±2.85	39.78 ±10.16	31.76 ±3.92	27.83 ±9.09
Root	48.24 ±9.99	47.88 ±16.13	41.22 ±4.91	29.82 ±1.57	23.68 ±1.40	8.19 ±0.87
Root nodule	12.99 ±1.23	28.85 3.43	29.46 ±2.76	25.32 ±7.68	13.09 ±3.54	11.38 ±2.12
Total	231.91 ±15.16	263.33 ±35.05	274.67 ±24.42	228.90 ±24.23	194.05 ±11.62	139.11 ±12.80
Cardamom						
Cardamom leaf	11.86 ±0.59	18.59 ±0.79	20.53 ±2.98	8.97 ±1.79	8.27 ±1.30	1.93 ±0.39
Pseudo-stem	26.89 ±6.30	41.91 ±6.33	46.41 ±9.37	20.12 ±5.25	18.78 ±5.24	4.36 ±0.75
Root/rhizome	48.76 ±7.04	60.86 ±18.60	96.26 ±34.13	39.55 ±7.76	36.30 ±10.83	7.82 ±0.92
Capsule	2.19 ±0.36	4.47 ±0.53	6.02 ±0.71	7.05 ±0.35	3.40 ±1.97	0.78 ±0.10
Total	89.70 ±16.11	125.83 ±21.91	169.22 ±38.20	75.69 ±10.51	66.75 ±1.64	14.89 ±1.99
Stand total	321.61 ±12.72	389.16 ±30.28	443.89 ±42.00	304.59 ±10.15	260.80 ±28.01	154.00 ±8.26

Table 4.8. Component wise transfer of energy (x 10^6 kJ ha^{-1} $year^{-1}$) to the stand floor through litter production in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.

Plant components	Stand age (year)					
	5	10	15	20	30	40
Tree						
Leaf and twig	66.73 ±1.25	85.14 ±2.51	117.78 ±1.40	99.78 ±6.07	92.47 ±3.35	66.32 ±4.18
Catkin	6.09 ±0.81	9.04 ±1.41	10.13 ±1.41	11.08 ±1.61	10.72 ±1.43	10.61 ±1.82
Total	72.82 ±3.41	94.18 ±2.10	127.91 ±3.45	110.86 ±4.65	103.19 ±5.43	76.93 ±4.34
Cardamom						
Cardamom leaf	11.86 ±5.84	18.59 ±7.95	20.53 ±3.06	8.97 ±1.81	8.27 ±1.42	1.93 ±0.48
Pseudo-stem	26.89 ±6.32	41.91 ±6.50	46.41 ±9.37	20.12 ±5.24	18.78 ±5.44	4.36 ±0.69
Total	38.75 ±7.54	60.50 ±4.45	66.94 ±5.21	29.09 ±2.32	27.05 ±2.11	6.29 ±0.56
Total	111.57 ±8.73	154.68 ±25.90	194.85 ±3.69	139.95 ±5.67	130.24 ±2.18	83.22 ±8.13

Table 4.9. Energy fixation, storage, allocation in agronomic yield, heat sink, release and exit, and efficiencies in an age series of *Alnus*-cardamom plantations.

Energy/efficiency	Stand age (year)					
	5	10	15	20	30	40
Energy storage ($\times 10^6$ kJ ha^{-1})	1053	1435	2341	2288	2292	2635
Stand energy content ($\times 10^6$ kJ ha^{-1})	774	1086	1815	1866	1926	2414
Energy Fixation ($\times 10^6$ kJ ha^{-1} year^{-1})	322	389	444	305	261	154
Net energy allocation in agronomic yield ($\times 10^6$ kJ ha^{-1} year^{-1})	2.19	4.47	6.02	7.05	3.40	0.78
Floor litter energy content ($\times 10^6$ kJ ha^{-1} year^{-1})	279	349	526	422	366	221
Heat sink from the floor ($\times 10^6$ kJ ha^{-1} year^{-1})	171	228	299	259	226	116
Energy exit ($\times 10^6$ kJ ha^{-1} year^{-1})	2.20	56.56	56.40	18.80	22.18	28.20
Energy conversion efficiency (%)	2.72	3.29	3.76	2.58	2.21	1.30
Energy fixation efficiency (GJ GJ^{-1} leaf energy year^{-1})	6.25	4.59	4.39	4.28	4.17	3.62
Net ecosystem energy increment ($\times 10^6$ kJ ha^{-1} year^{-1})	148.8	104.4	88.6	27.2	12.8	9.8
Energy accumulation ratio	3.27	3.69	5.27	7.5	8.78	17.11
Energy efficiency in N_2-fixation (g N_2 fixed 10^4 kJ^{-1} energy)	64	71	76	73	71	84
Energy utilized per kg N_2 fixed ($\times 10^4$ kJ)	16	14	13	13	14	12

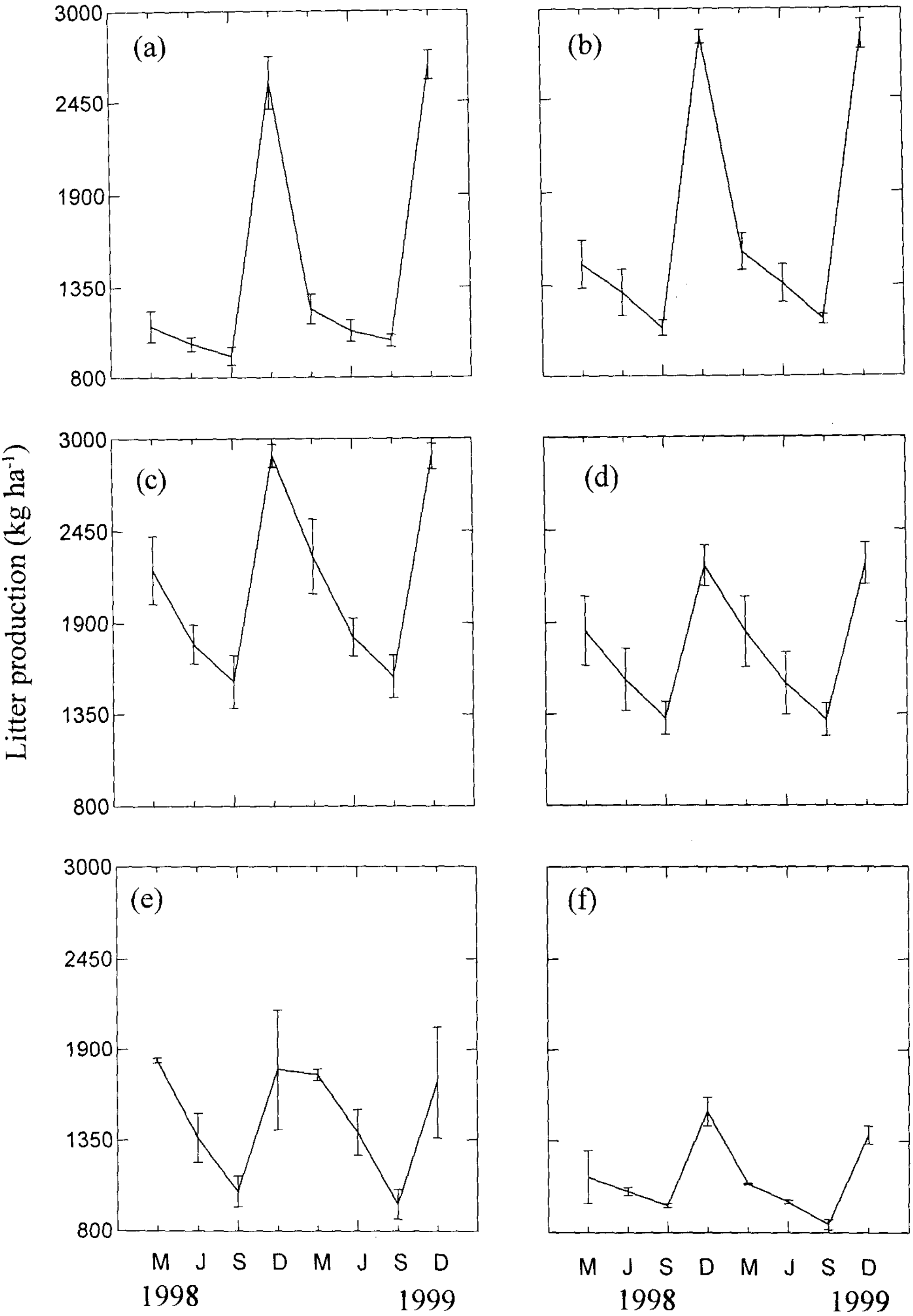


Fig. 4.1. Temporal distribution of litter production in (a) 5-year, (b) 10-year, (c) 15-year, (d) 20-year, (e) 30-year and (f) 40-year of *Alnus*-cardamom plantation stands. Vertical bars represent standard errors.

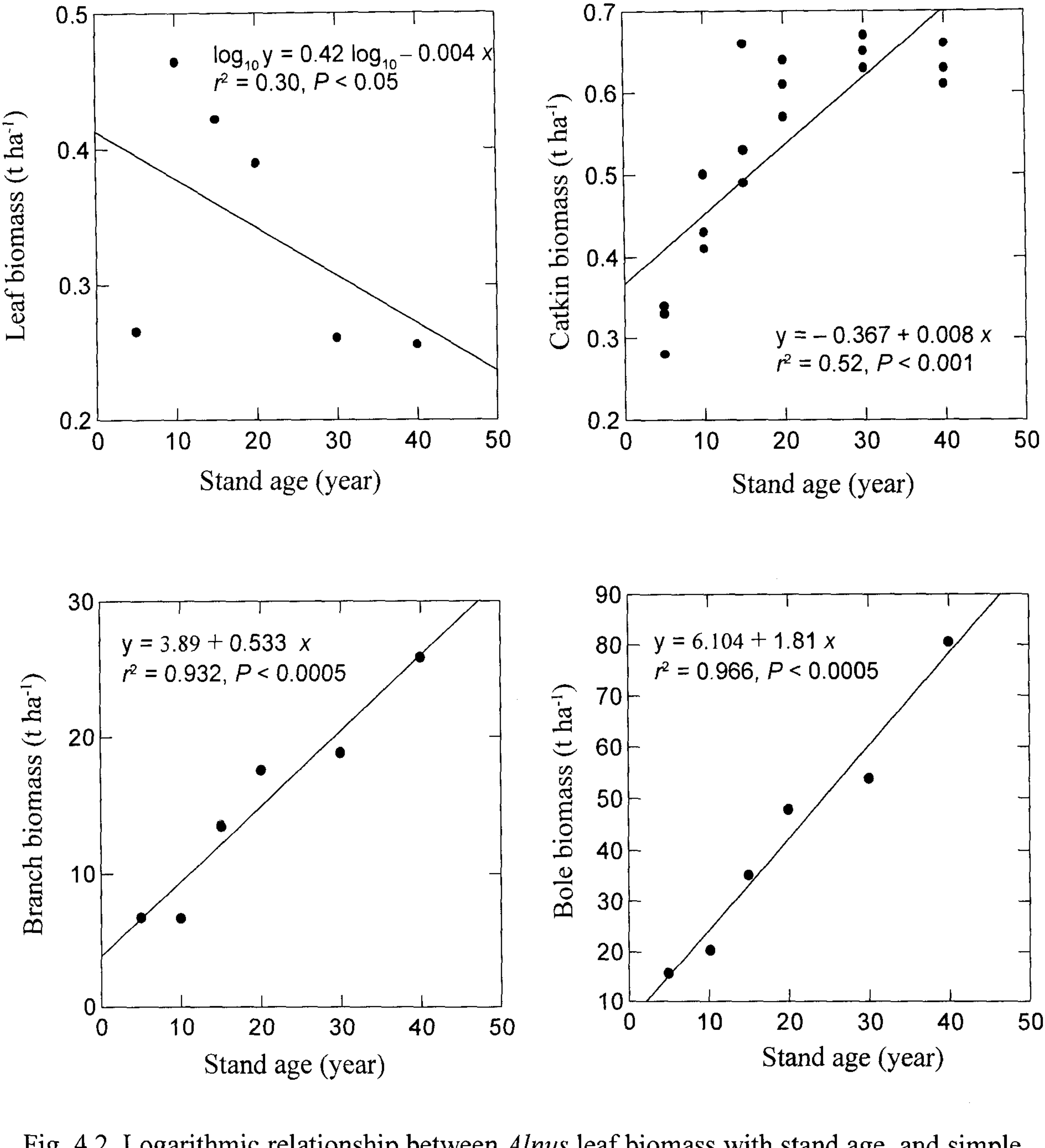


Fig. 4.2. Logarithmic relationship between *Alnus* leaf biomass with stand age, and simple relationships between catkin, branch and bole biomass of *Alnus* with stand age in the age series of *Alnus*-cardamom palntation stands.Values are means of three site replicates.

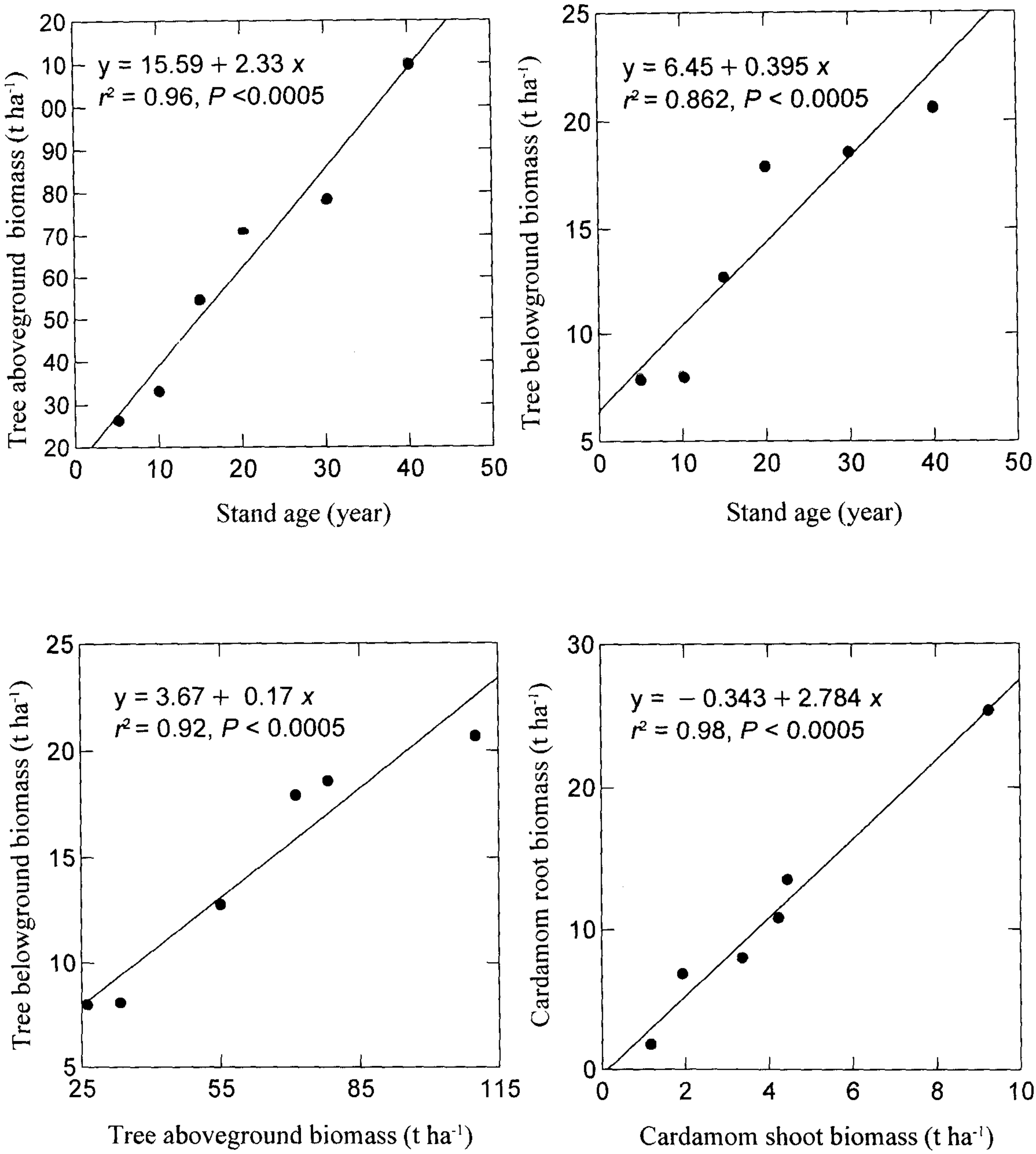


Fig. 4.3. Relationships between abovegound and belowground tree biomass with stand age, tree belowground biomass with aboveground biomass, and cardamom root biomass with cardamom shoot biomass in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.

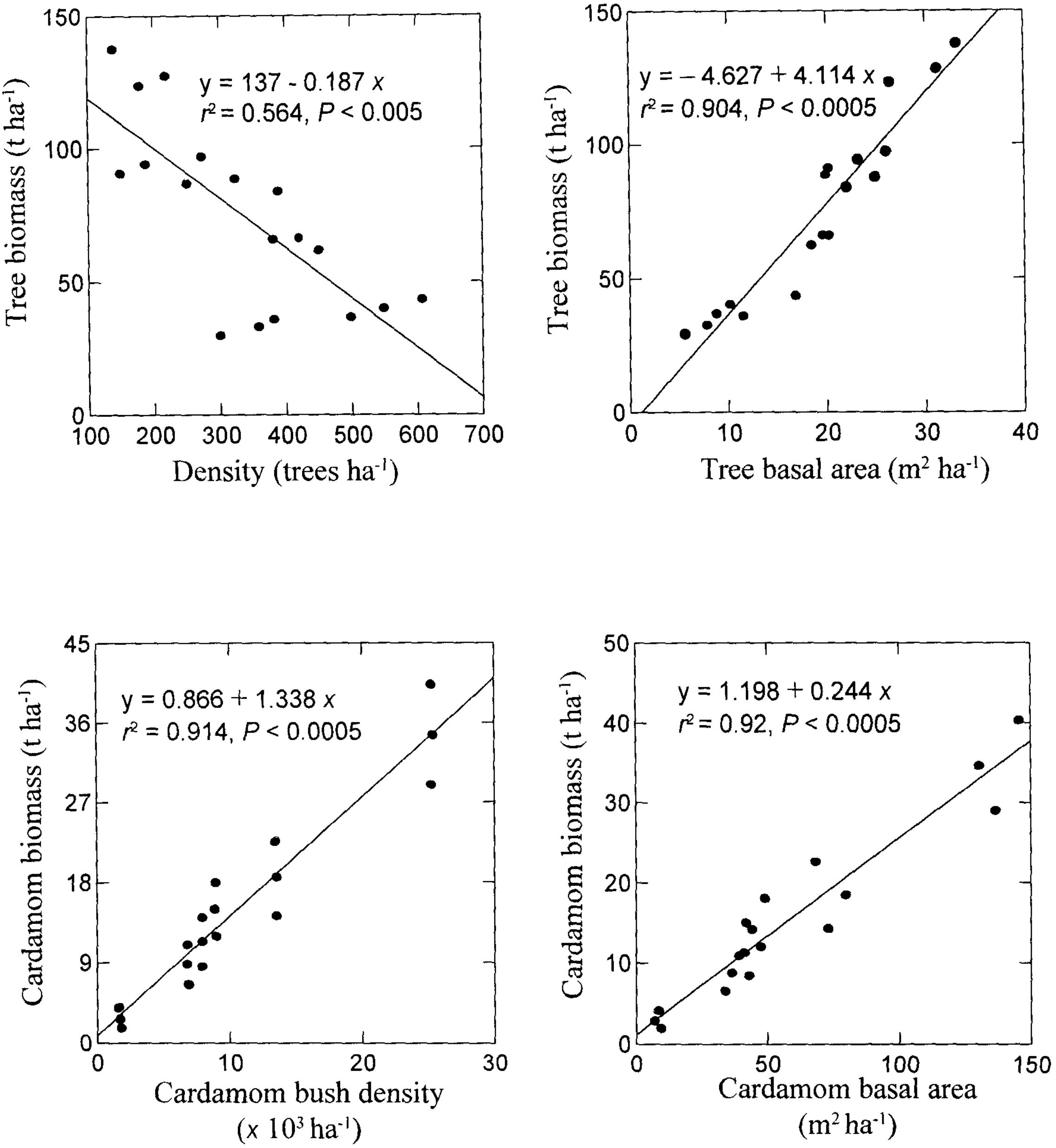


Fig. 4.4. Relationships between standing tree density and tree basal area with tree biomass, and cardamom basal area and cardamom bush density with cardamom biomass in an age seires of *Alnus*-cardamom plantation stands.

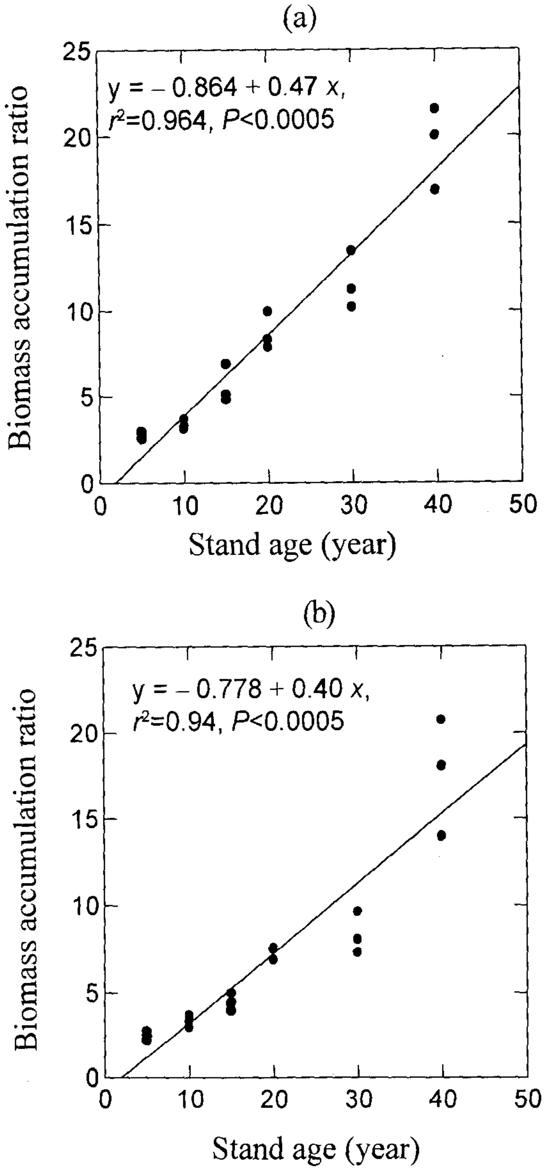


Fig. 4.5. Relationships between biomass accumulation ratio of (a) *Alnus* and (b) stand total with stand age in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.

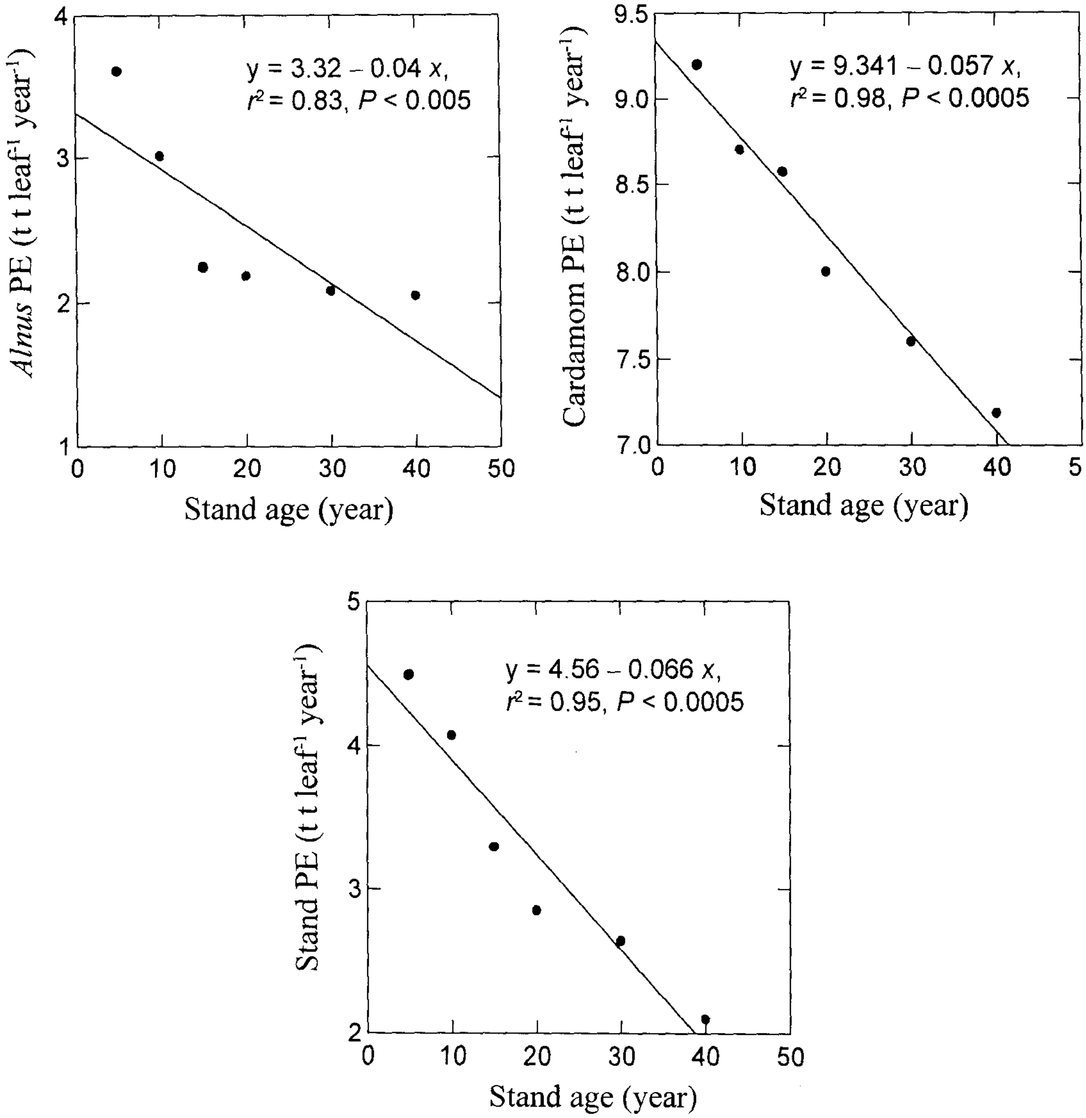
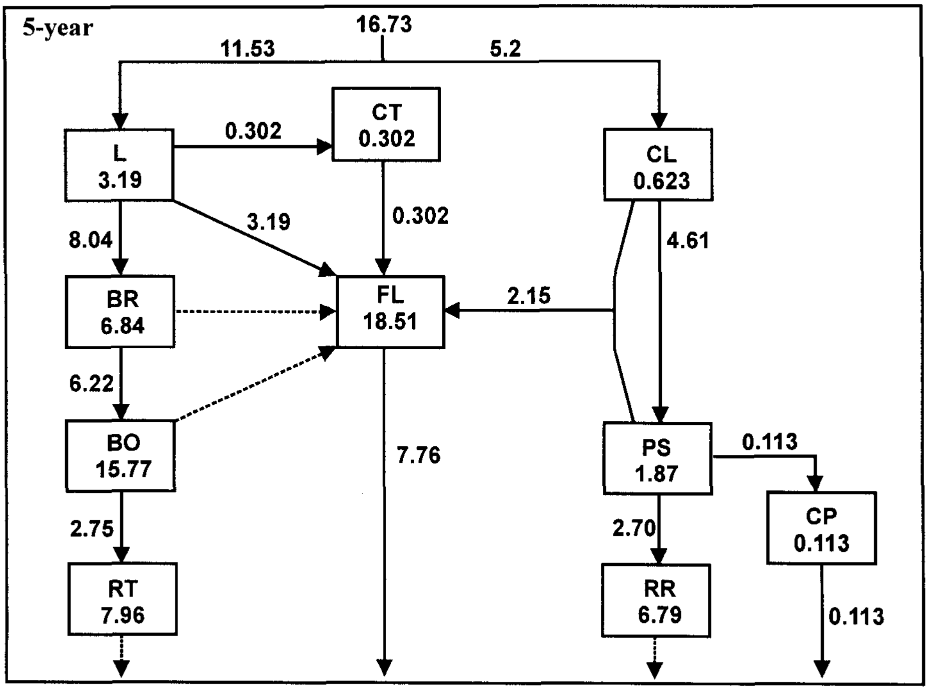
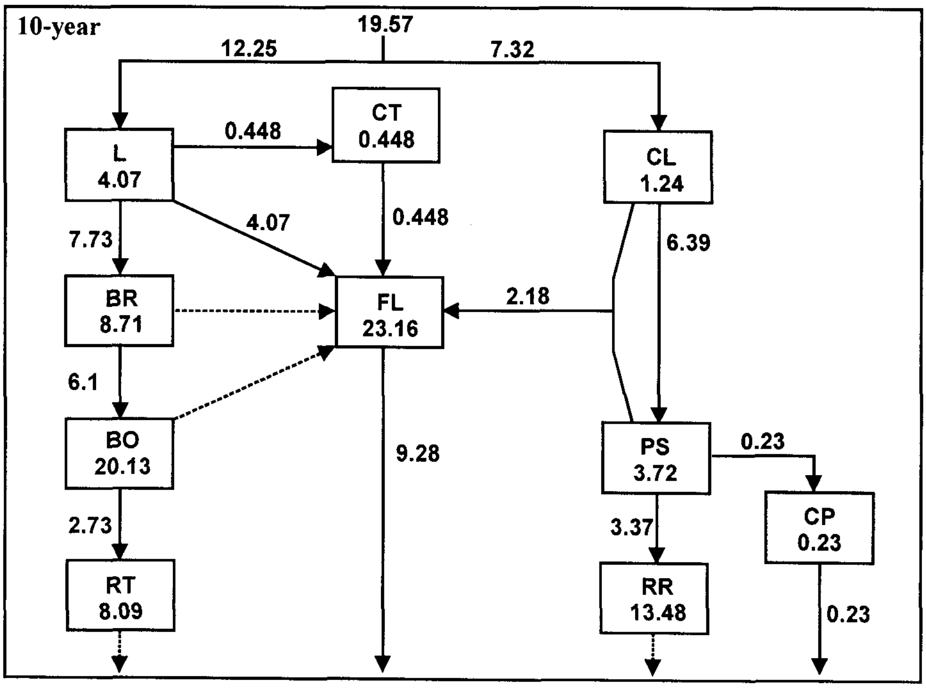


Fig. 4.6. Relationships between production efficiency (PE) of shade tree *Alnus*, cardamom and stand total with stand age in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.

Fig. 4.7a. Compartment model showing distribution of dry matter biomass, net primary production, litter disappearance rate and cardamom capsule harvest in 5- and 10-year stand of *Alnus*-cardamom plantations. Broken lines indicate that values are not estimated. Units are t h^{-1} for compartments and t ha^{-1} $year^{-1}$ for flows. L= leaf, BR= branch, BO= bole, RT= root, CT= catkin, FL= floor litter, CL= cardamom leaf, PS= pseudo-stem, RR= root/rhizome, CP= cardamom capsule.

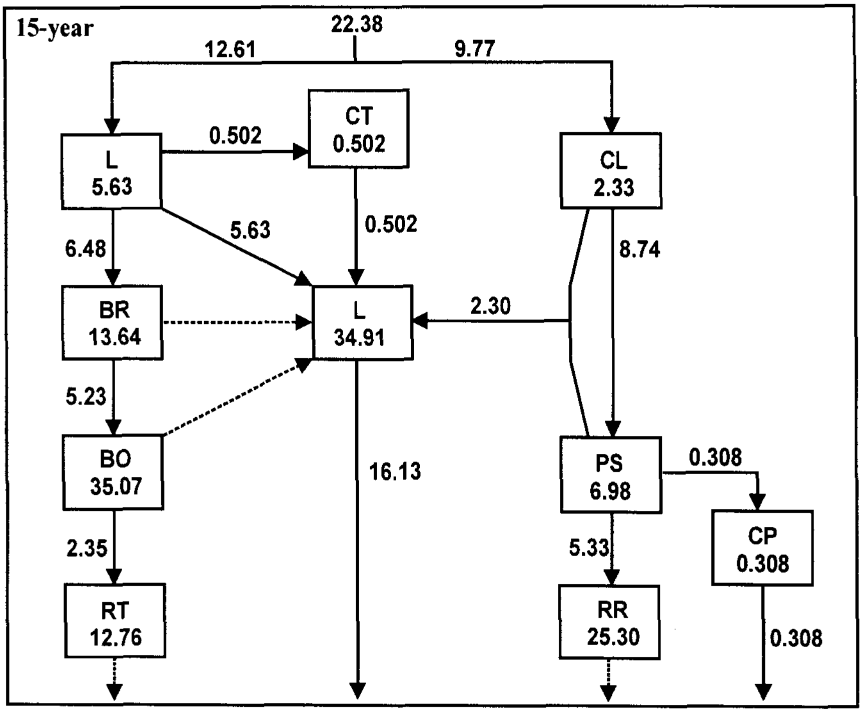


5-year
16.73
11.53
5.2
L
3.19
0.302
CT
0.302
CL
0.623
3.19
0.302
8.04
4.61
BR
6.84
FL
18.51
2.15
6.22
BO
15.77
7.76
PS
1.87
0.113
CP
0.113
2.75
2.70
RT
7.96
RR
6.79
0.113



10-year
19.57
12.25
7.32
L
4.07
0.448
CT
0.448
CL
1.24
4.07
0.448
7.73
6.39
BR
8.71
FL
23.16
2.18
6.1
BO
20.13
9.28
PS
3.72
0.23
CP
0.23
2.73
3.37
RT
8.09
RR
13.48
0.23

Fig. 4.7b. Compartment model showing distribution of dry matter biomass, net primary production, litter disappearance rate and cardamom capsule harvest in 15- and 20-year stand of *Alnus*-cardamom plantations. Broken lines indicate that values are not estimated. Units are t h^{-1} for compartments and t ha^{-1} $year^{-1}$ for flows. L= leaf, BR= branch, BO= bole, RT= root, CT= catkin, FL= floor litter, CL= cardamom leaf, PS= pseudo-stem, RR= root/rhizome, CP= cardamom capsule.


15-year
22.38
12.61
9.77
L
5.63
0.502
CT
0.502
CL
2.33
5.63
0.502
6.48
8.74
BR
13.64
L
34.91
2.30
5.23
BO
35.07
16.13
PS
6.98
0.308
CP
0.308
2.35
5.33
RT
12.76
RR
25.30
0.308

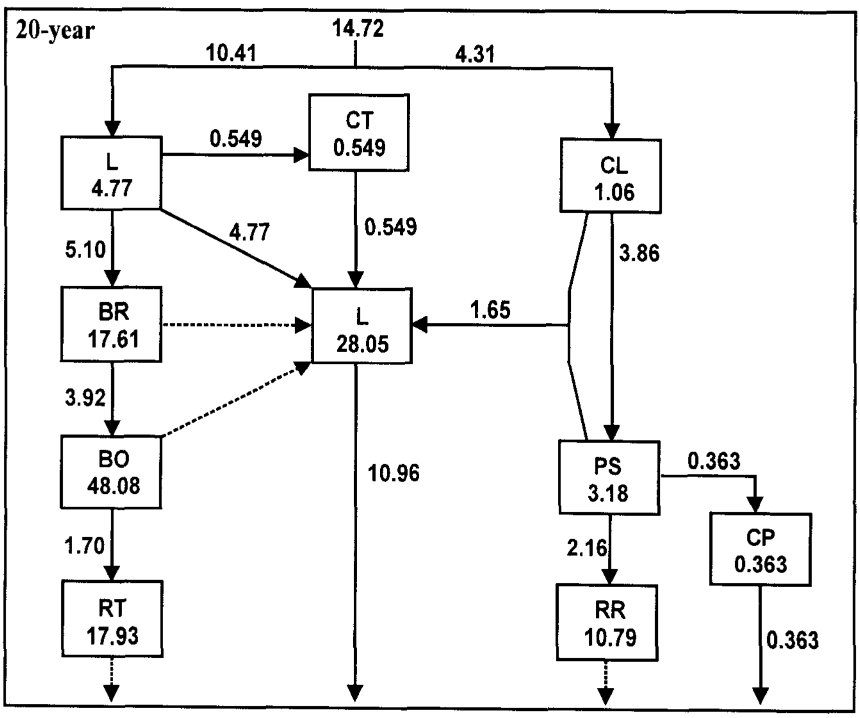
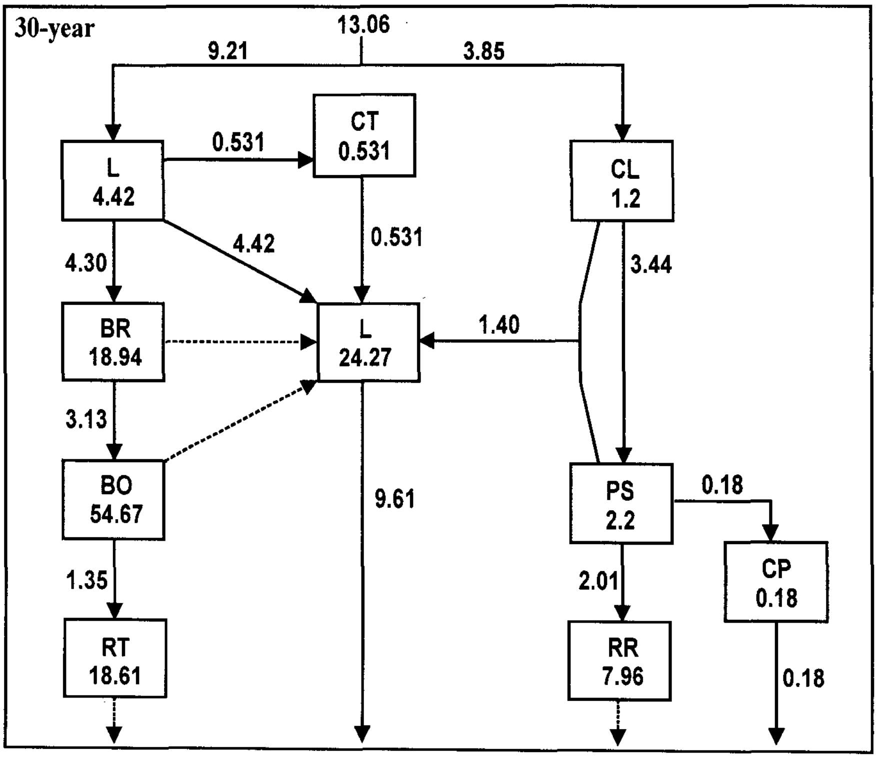

20-year
14.72
10.41
4.31
L
4.77
0.549
CT
0.549
CL
1.06
4.77
0.549
5.10
3.86
BR
17.61
L
28.05
1.65
3.92
BO
48.08
10.96
PS
3.18
0.363
CP
0.363
1.70
2.16
RT
17.93
RR
10.79
0.363

Fig. 4.7c. Compartment model showing distribution of dry matter biomass, net primary production, litter disappearance rate and cardamom capsule harvest in 30- and 40-year stand of *Alnus*-cardamom plantations. Broken lines indicate that values are not estimated. Units are t h^{-1} for compartments and t ha^{-1} $year^{-1}$ for flows. L= leaf, BR= branch, BO= bole, RT= root, CT= catkin, FL= floor litter, CL= cardamom leaf, PS= pseudo-stem, RR= root/rhizome, CP= cardamom capsule.


30-year
13.06
9.21
3.85
L
4.42
0.531
CT
0.531
CL
1.2
4.30
4.42
0.531
3.44
BR
18.94
L
24.27
1.40
3.13
BO
54.67
9.61
PS
2.2
0.18
1.35
2.01
CP
0.18
RT
18.61
RR
7.96
0.18

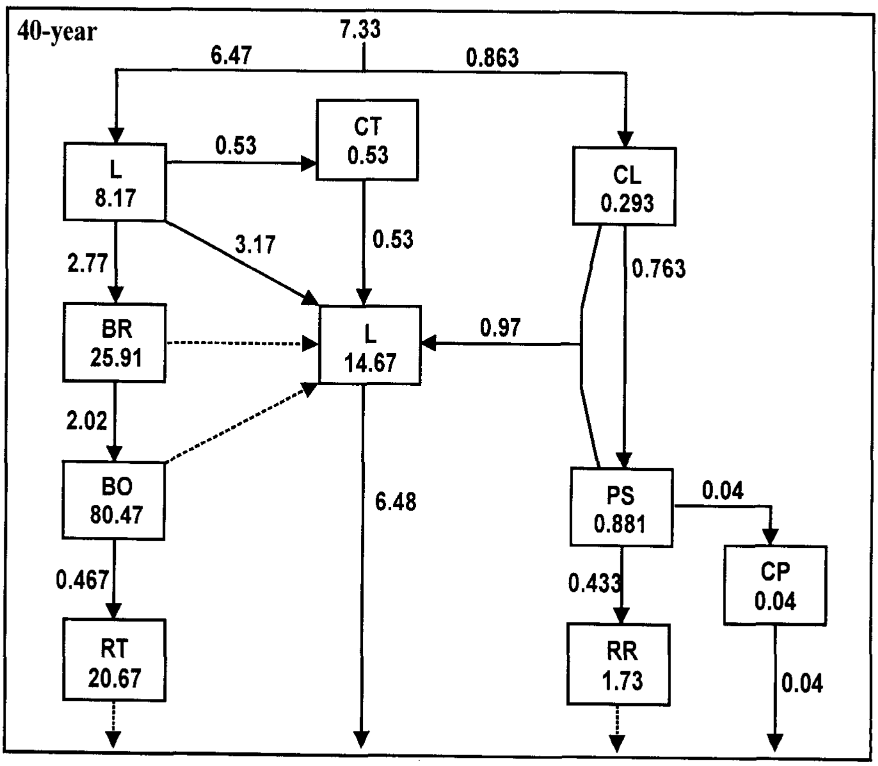
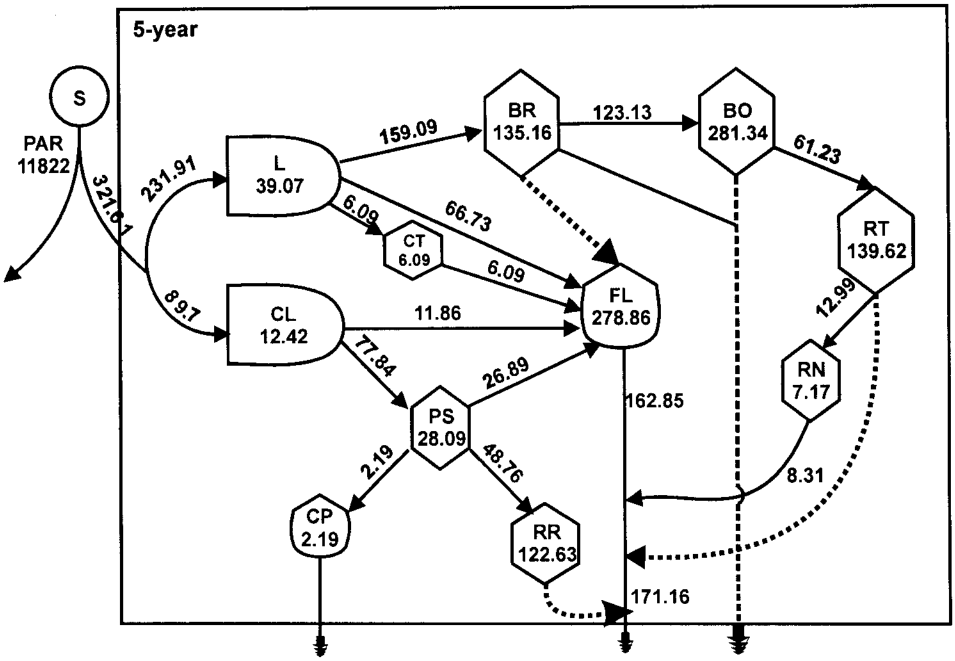

40-year
7.33
6.47
0.863
L
8.17
0.53
CT
0.53
CL
0.293
2.77
3.17
0.53
0.763
BR
25.91
L
14.67
0.97
2.02
BO
80.47
6.48
PS
0.881
0.04
0.467
0.433
CP
0.04
RT
20.67
RR
1.73
0.04

Fig. 4.8a. Distribution of energy storage in components, net energy flow and heat sink from the stand floor in 5- and 10-year–old *Alnus*-cardamom plantation stands. Units are $\times 10^6$ kJ ha^{-1} for compartments and $\times 10^6$ kJ ha^{-1} $year^{-1}$ for flows. Broken lines indicate that values are not estimated. PAR=photosynthetically active radiation; S=sun; L=*Alnus* leaf; CT=catkin; BR=branch; BO=bole; RT=root; RN=root nodule; FL=floor litter; CL=cardamom leaf; PS=pseudo-stem; RR=root/rhizome; and CP=cardamom capsule. This figure is drawn using the symbols given by Odum and Odum (1976).


5-year
S
PAR
11822
321.61
231.91
89.7
L
39.07
CL
12.42
159.09
BR
135.16
123.13
BO
281.34
61.23
RT
139.62
66.73
6.09
CT
6.09
6.09
11.86
FL
278.86
77.84
PS
28.09
26.89
2.19
48.76
CP
2.19
RR
122.63
162.85
171.16
12.99
RN
7.17
8.31

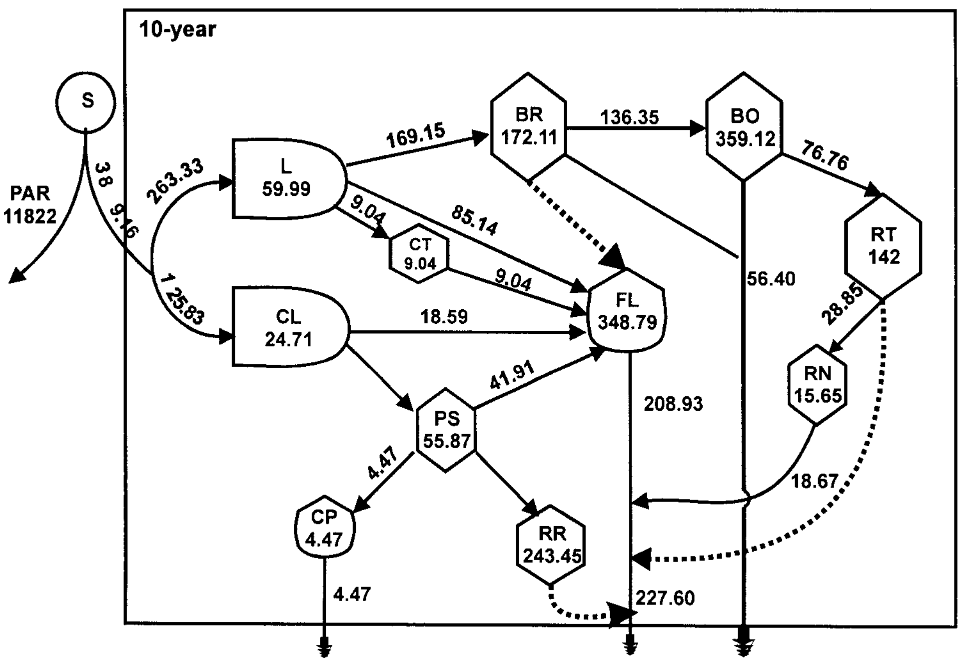
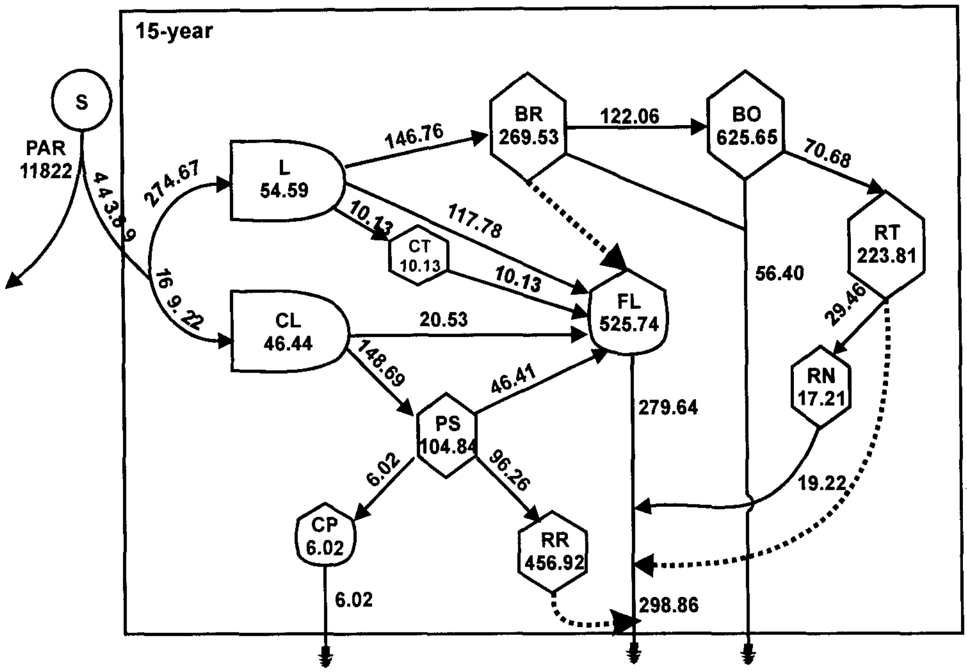

10-year
S
PAR
11822
38 9.16
263.33
1 25.83
L
59.99
CL
24.71
169.15
BR
172.11
136.35
BO
359.12
76.76
RT
142
85.14
9.04
CT
9.04
9.04
18.59
FL
348.79
PS
55.87
41.91
4.47
CP
4.47
4.47
RR
243.45
208.93
227.60
56.40
28.85
RN
15.65
18.67

Fig. 4.8b. Distribution of energy storage in components, net energy flow and heat sink from the stand floor in 15- and 20-year-old *Alnus*-cardamom plantation stands. Units are $\times 10^{6}$ kJ ha^{-1} for compartments and $\times 10^{6}$ kJ ha^{-1} $year^{-1}$ for flows. Broken lines indicate that values are not estimated. PAR=photosynthetically active radiation; S=sun; L=*Alnus* leaf; CT=catkin; BR=branch; BO=bole; RT=root; RN=root nodule; FL=floor litter; CL=cardamom leaf; PS=pseudo-stem; RR=root/rhizome; and CP=cardamom capsule. This figure is drawn using the symbols given by Odum and Odum (1976).


15-year
S
PAR
11822
44 3.8 9
274.67
16 9.22
L
54.59
CL
46.44
146.76
BR
269.53
122.06
BO
625.65
70.68
117.78
10.13
CT
10.13
10.13
20.53
FL
525.74
56.40
RT
223.81
29.46
148.69
46.41
PS
104.84
279.64
RN
17.21
6.02
96.26
19.22
CP
6.02
RR
456.92
6.02
298.86

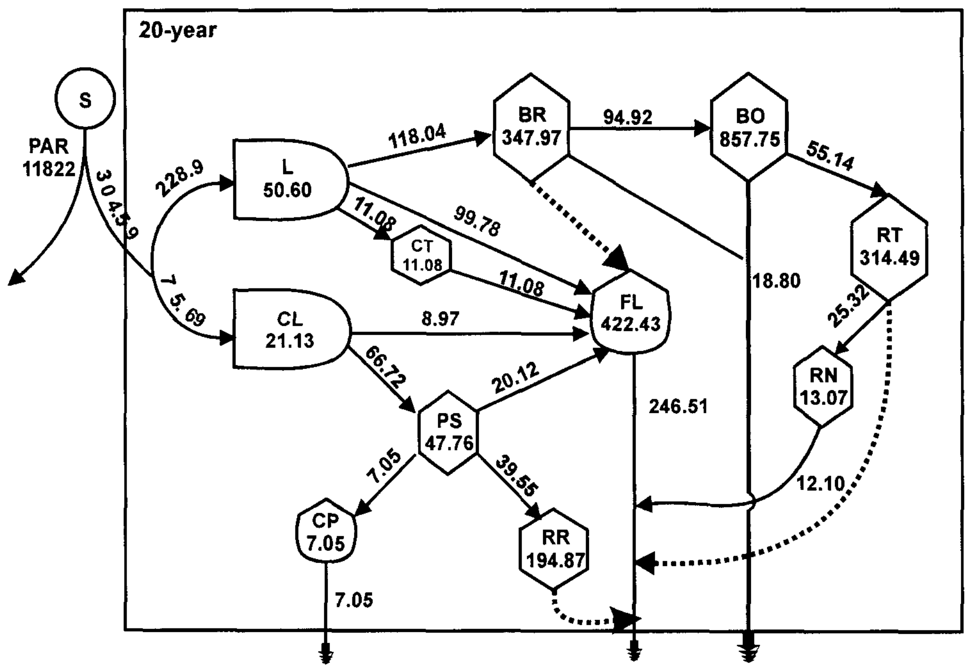
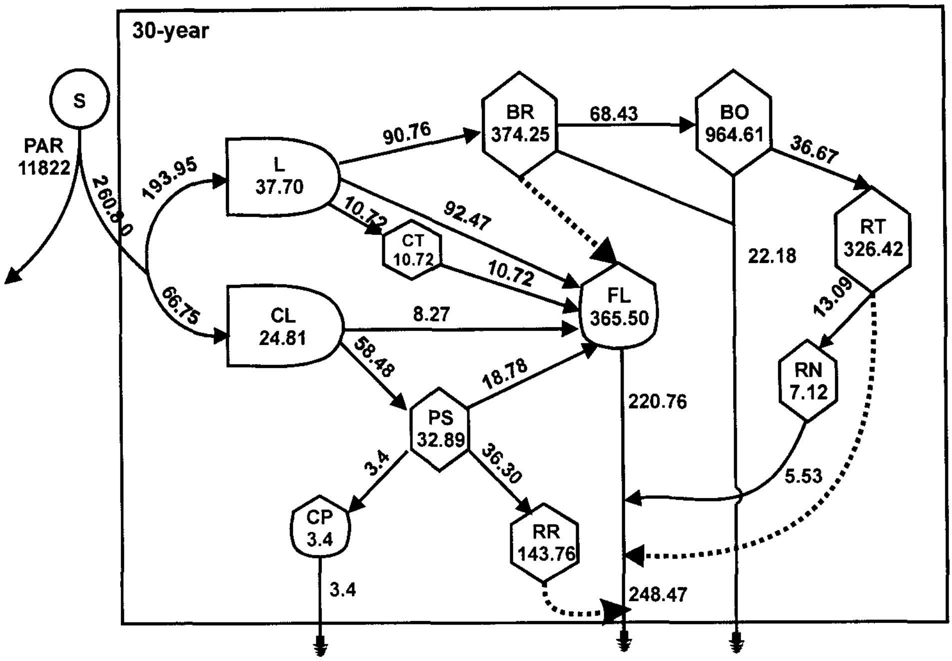
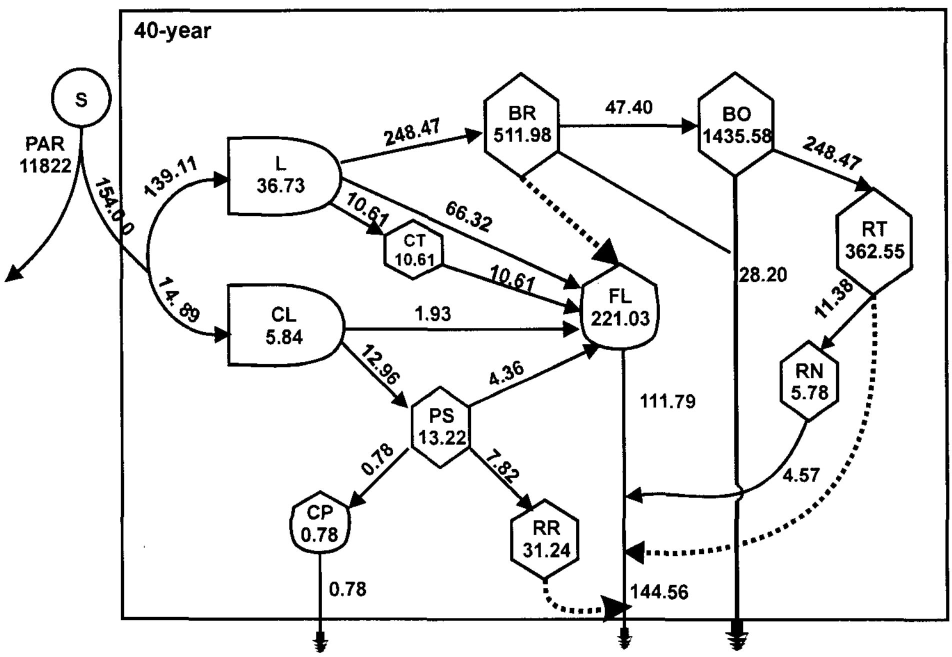

20-year
S
PAR
11822
30 4.5 9
228.9
7 5.69
L
50.60
CL
21.13
118.04
BR
347.97
94.92
BO
857.75
55.14
99.78
11.08
CT
11.08
11.08
8.97
FL
422.43
18.80
RT
314.49
25.32
66.72
20.12
PS
47.76
246.51
RN
13.07
7.05
39.55
12.10
CP
7.05
RR
194.87
7.05

Fig. 4.8c. Distribution of energy storage in components, net energy flow and heat sink from the stand floor in 30- and 40-year-old *Alnus*-cardamom plantation stands. Units are $\times 10^{6}$ kJ ha^{-1} for compartments and $\times 10^{6}$ kJ ha^{-1} $year^{-1}$ for flows. Broken lines indicate that values are not estimated. PAR=photosynthetically active radiation; S=sun; L=*Alnus* leaf; CT=catkin; BR=branch; BO=bole; RT=root; RN=root nodule; FL=floor litter; CL=cardamom leaf; PS=pseudo-stem; RR=root/rhizome; and CP=cardamom capsule. This figure is drawn using the symbols given by Odum and Odum (1976).


30-year
S
PAR
11822
260.8.0
193.95
66.75
L
37.70
CL
24.81
90.76
92.47
10.72
CT
10.72
10.72
8.27
58.48
BR
374.25
68.43
BO
964.61
36.67
RT
326.42
22.18
FL
365.50
13.09
RN
7.12
18.78
PS
32.89
220.76
3.4
36.30
5.53
CP
3.4
RR
143.76
3.4
248.47


40-year
S
PAR
11822
154.0.0
139.11
14.89
L
36.73
CL
5.84
248.47
66.32
10.61
CT
10.61
10.61
1.93
12.96
BR
511.98
47.40
BO
1435.58
248.47
RT
362.55
28.20
FL
221.03
11.38
RN
5.78
4.36
PS
13.22
111.79
0.78
7.82
4.57
CP
0.78
RR
31.24
0.78
144.56

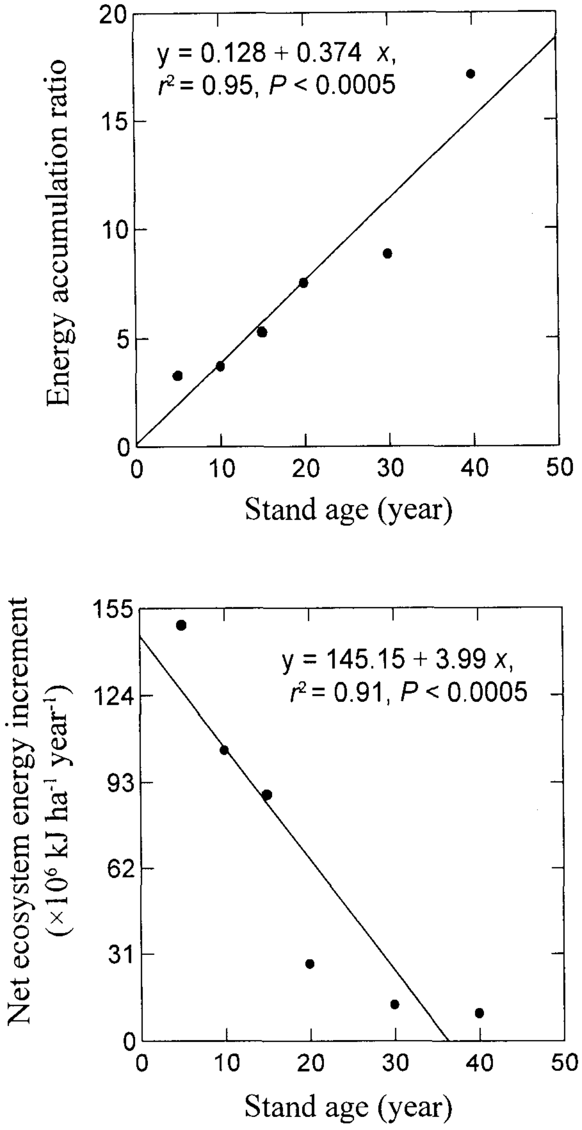


Fig. 4.9. Relationships between energy accumulation ratio and net ecosystem energy increment with stand age in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.

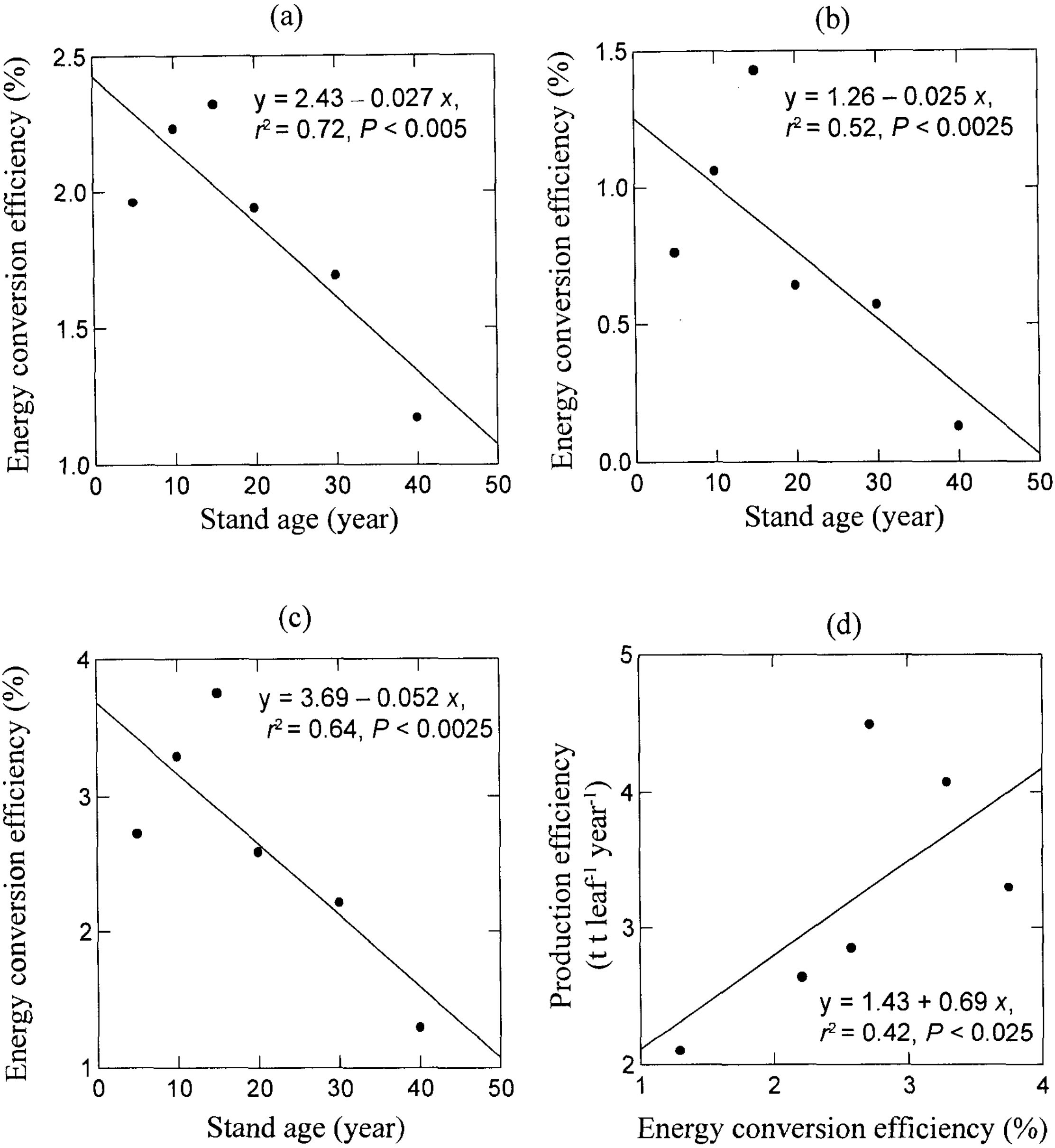
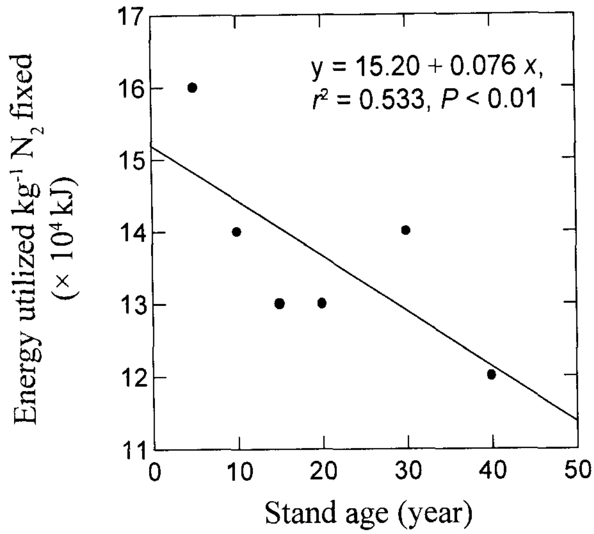


Fig. 4.10. Relationships between energy conversion efficiency (%) of shade tree *Alnus* with stand age (a), understorey cardamom with stand age (b) and plantation stand as a whole with stand age (c), and (d) relationship between production efficiency and energy conversion efficiency in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.



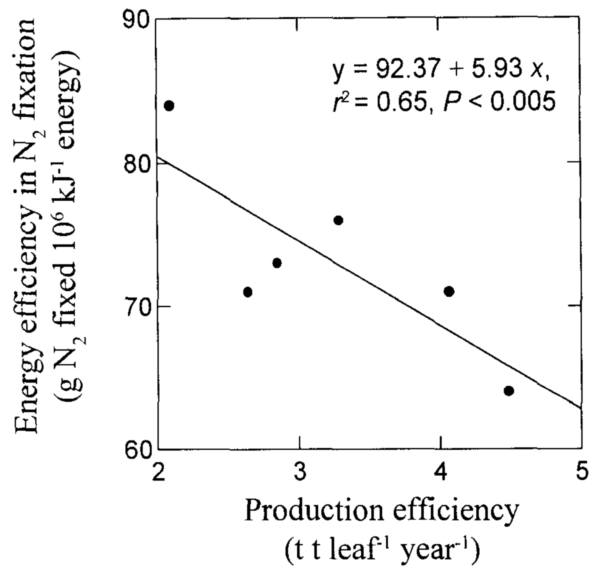


Fig. 4.11. Relationships between energy utilized per kg N_2 fixed with stand age, and energy efficiency in N_2-fixation with production efficiency in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.