STAND NUTRIENT DYNAMICS

8.1 Introduction

Nutrient elements play fundamental roles in physiological activities of plants. The primary production of plantations is influenced by the availability of nutrients, and this in turn depends on distribution and rates of cycling. Concentration of nutrients within any part of an ecosystem usually depends upon a functional balance within the system. Information is scanty on the functional balance of nutrients within ecosystems where mixtures of N_2-fixing and non-N_2-fixing plants are managed.

Recently, agroforestry systems are strengthened by incorporating the N_2-fixing tree species as an intervention for influencing the soil fertility. A considerable study on the effects of N_2-fixing *Alnus* (Binkley *et al.* 1992a; Carlson and Dawson 1985; Sharma and Ambasht 1991; Bashkin and Binkley 1998; Garcia-Montiel and Binkley 1998) in agroforestry and N_2-fixing *Albizia* in *Eucalyptus* plantations (DeBell *et al.* 1989; Dukin 1989; Binkley and Giardina 1997) are available. Agroforestrey systems are dynamic in nutrient fluxes compared to forests, but studies on biogeochemical fluxes in such agroforestry systems are lacking.

Nutrient dynamics in relation to plantation age is quite important, given that the structure and functions of plantations do not remain constant as stands mature. This was reported in pure monoculture plantations of alder (Sharma 1993) in the Himalaya and lodgepole pine (Binkley *et al.* 1995) in North America. Binkley *et al.* (1992b) and DeBell *et al.* (1997) have studied nutrient availability and performance of mixtures of different percentage combinations of N_2-fixing *Albizia* and non-N_2-fixing *Eucalyptus*. However, information on nutrient dynamics for mixtures of N_2-fixing and non-N_2-fixing stands with respect to stand age and maturity is limiting. Establishment of plantation mixtures (agroforestry) of large cardamom (*Amomum subulatum* Roxb.) and N_2-fixing Himalayan alder (*Alnus nepalensis* D. Don) is a common practice in the eastern Himalaya. These *Alnus*-cardamom plantations form a good system for understanding the impact of stand age on performance of mixtures of N_2-fixing and non-N_2-fixing plants.

This chapter deals with studies on concentration, standing state, uptake, return, turnover and cycling of nutrients, nutrient use efficiency and nitrogen accretion through fixation in an age series of plantation mixtures of *Alnus* and cardamom in the Sikkim Himalaya.

8.2 Materials and methods

8.2.1 Field sampling and nutrient analysis

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. All plant and soil samplings were made from these sample plots. Plant samples of different components (leaf, twig, catkin, branch, bole, root and root nodules of *Alnus*, and leaf, pseudo-stem, capsule, rhizome and root of cardamom) were collected in replicates (n=9; 3 samples × 3 site replicates) from all the six age group stands. These samples were oven dried at 80°C to a constant weight for determining fresh weight to dry weight ratios and ground to pass a 2-mm sieve. Total-N in these samples was analyzed using modified Kjeldahl method and P by ascorbic acid method (Anderson and Ingram 1993). Nutrient retranslocation during the senescence of leaf and twigs from the *Alnus* tree was analyzed by taking the difference of nutrients in intact and senescent parts (Rawat and Singh 1988).

Soil samples were collected for 0-15 and 15-30 cm depths from all the 18 plots representing six age groups during rainy, winter and spring seasons (see Chapter VII). Samples were air dried, ground to pass through a 2-mm sieve and used for nutrient analysis. Soil total-N and total-P were estimated by modified Kjeldahl and ascorbic acid methods, respectively (Anderson and Ingram 1993). The amount of nutrients in each horizon (0-15 and 15-30 cm) of soil was estimated using bulk density, soil volume and nutrient concentration values. The amount of nutrients estimated in both the horizons was summed to obtain total nutrient contents down to 30-cm depth.

8.2.2. Nutrients standing states and flow rates

Standing biomass, net primary productivity, litter production and cardamom yield are presented in Chapter IV and were used for quantifying nutrient contents in different plant components, floor-litter and their flow rates. Nutrient contents in different plant components were obtained by multiplying dry weight of components with their mean nutrient concentration. Monthly tree litterfall estimation was carried out for a 2-year period (1998-1999) using five litter traps of 1 m^2 collecting area in each sample plot and pooled to annual values. Cardamom tillers that have fruited in the current year were slashed to remain on the stand floor after the harvest as a management practice because it does not fruit again. Nutrient flow from tree litterfall and slashed cardamom tillers was estimated by multiplying with the nutrient concentration. The mean nutrient content of the floor litter was estimated by analyzing samples in different layers at five random (1×1 m) areas in each of the plots. Decomposition rates were calculated by enclosing litter fractions separately in nylon bags, and values of all the fractions pooled to achieve annual nutrient release.

Root nodules of five average sized *Alnus* trees from all the 18 plots were recovered for estimation of biomass and nutrient contents. Nutrient release from the root nodules of *Alnus* was estimated using nodule turnover and decomposition rate conversion factor (Sharma and Ambasht 1986b) and nutrient concentration in root nodules.

8.2.3. Computation of nutrient uptake, retention, return and turnover time

The values of nutrient contents of different plant components of both *Alnus* and cardamom were summed to obtain nutrient storage in vegetation. The sum of nutrient contents of *Alnus* trees, understorey cardamom and floor-litter represented standing state of a stand. The annual nutrient uptake was the sum of the production of nutrients in all plant components. In the case of nitrogen, the difference between total annual uptake and fixation in a stand was the net uptake from the soil. Nutrient retention was the difference between annual uptake and return through decomposition of the stand floor-litter and root nodules. Turnover time of nutrients in the standing vegetation was computed by taking the ratios of standing state and the annual uptake (Chaturvedi and Singh 1987; Sharma 1993). The turnover time for each nutrient on stand floor was calculated following Olson (1963).

8.3 Results

8.3.1. Nutrient concentrations and standing states

Nutrient concentrations of *Alnus* and cardamom components in the age series of *Alnus*-cardamom plantations are presented in Table 8.1 & 8.2. Concentrations of nutrients were highest in leaves and lowest in boles of *Alnus*, and highest in leaves and lowest in rhizomes of cardamom. The highest concentration of N in *Alnus* leaf was 11 times greater than the lowest concentration in the bole, while seven times greater in leaf than that of rhizome in cardamom. Tremendous variation of about 100 times greater P concentration was recorded in leaf (highest value) compared to bole (lowest value) of *Alnus*, and about 84 times greater in leaf than rhizome of cardamom. Mean N concentrations of different components of *Alnus* tree decreased in the order leaf>catkin>root>twig>branch>bole, similar order was recorded for P except higher concentration in twig than root. In cardamom, it followed the order leaf>capsule>root>pseudo-stem≈rhizome for N, and similar trend for P was recorded with distinctly higher value in pseudo-stem than rhizome. Foliar nutrient concentrations of *Alnus* decreased with the advancing age groups of plantations and showed inverse relationships with stand age (Fig. 8.1). Both N- and P-concentrations of foliage, decreased by about one-fourth in the 40-year stand to that of the 5-year stand.

Stand total and component wise standing stocks of nutrients are presented in Table 8.3. Standing states of N increased from the 5-year stand conspicuously which doubled by the 15-year stand, and then slightly increased to be highest at the 40-year stand. It was 2.43 times greater in the 40-year stand than that of the 5-year stand. Standing state of P also increased by 2.5 times from the 5-year stand to the 15-year stand, and then decreased to a value of 7 kg ha^{-1} in the 40-year stand. Increment in perennial parts such as branch, bole and root of *Alnus* mainly contributed nutrient buildup in biomass. The contribution of different components of cardamom to the standing state decreased after 15-year stand with advancing age.

Standing states of N including that of floor-litter was recorded lower (554 kg ha^{-1}) in the 5-year stand to a highest value (1084 kg ha^{-1}) in the 15-year stand, thereafter it slightly decreased in the advancing age. Phosphorus in the standing states was also recorded highest (48 kg ha^{-1}) in the 15-year stand, it increased from 5-year to the greatest value at the 15-year stand and then declined with advancing age.

8.3.2. Nutrient return to floor and turnover rates

Annual inputs of nutrients to the floor was mainly contributed by litterfall of *Alnus* (leaf and twig, and catkin) and slashed cardamom tillers (Table 8.4). Total nutrient return to stand floor from both *Alnus* and cardamom ranged from 3.57 kg ha^{-1} $year^{-1}$ P and 62 kg ha^{-1} $year^{-1}$ N in the 40-year stand to 7.35 kg ha^{-1} $year^{-1}$ P and 163 kg ha^{-1} $year^{-1}$ N in the 15-year stand (Table 8.4). The contribution of *Alnus* leaf and twig for both the nutrients was always highest (59–69% N; 45–62% P) in all the stands. The contribution of cardamom leaf and pseudo-stem ranged from 17–44% P and 17–32% N. Floor-litter biomass and its nutrient contents increased from the 5-year to a highest value at the 15-year and declined to a lowest value at the 40-year stand (Table 8.5). Nitrogen in the floor litter was 2.48–3.43 times greater and P

2.54–4.51 times greater than the annual input through litterfall and slashed cardamom tillers.

The values of turnover rates and times for different nutrients on the stand floor are given in Table 8.6. The turnover time of N ranged from 2.5 years in the 5-year stand to 3.4 years in the 30-year stand. P turnover time also ranged from a similar minimum value of 2.5 years at the 5-year stand to a highest value of 4.5 years at the 15-year stand. Turnover rate of N ranged from 0.29 in the 30-year stand to 0.40 in the 5-year stand, and P ranged from 0.22 in 15- and 20-year stand to 0.39 at the 5-year stand.

8.3.3. Nutrient uptake, retranslocation and turnover time

Nutrient uptake from the soil, retention in biomass and return to the soil, and standing states in the age series of plantation stands are presented in Table 8.7. Cardamom tillers that have fruited in any year are slashed immediately as a management practice because it does not fruit again. Nitrogen uptake that included addition through biological fixation was lowest (90 kg ha^{-1} $year^{-1}$) in the 40-year stand and highest (239 kg ha^{-1} $year^{-1}$) in the 15-year stand. Phosphorus uptake also showed similar pattern having the lowest value (3.83 kg ha^{-1} $year^{-1}$) at the 40-year stand and highest (10.60 kg ha^{-1} $year^{-1}$) at the 5-year stand. Annual return of N to the soil through decomposition to that of uptake ranged from 32–58% being higher in younger stands whereas P ranged from 44–66% being highest at 15- and 20-year stands.

Nutrient retranslocation from the senescent *Alnus* leaves is presented in Fig. 8.3a, b & c and 8.4a, b & c. Nitrogen retranslocation rates were lower in the youngest stand and it increased with plantation age. In the case of P, reverse was recorded having higher values in the youngest plantation that decreased with advancing age. Nitrogen retranslocation showed strong positive relationship with stand age while the relationship was inverse in P (Fig. 8.5).

Turnover time (year) of nutrients in the standing vegetation in the age series of *Alnus*-cardamom is presented in Table 8.8. Turnover time of N in the standing vegetation of both *Alnus* and cardamom increased from 1.83 years at the 5-year stand through subsequent ages to a highest value of 8.32 years at the 40-year stand. Overall turnover time for P was low ranging from 1.1 years in the 5-year stand to 1.83 years in the 40-year stand. The turnover time of both the nutrients was not much variable in cardamom components; however N turnover time increased tremendously after 15-year stand in *Alnus* whereas P remained nearly the same.

8.3.5. Nutrient use efficiency and nutrient cycling

Nutrient use efficiency (kg annual net primary productivity per kg nutrient taken up) for both N and P decreased with plantation age (Table 8.9). Nitrogen use efficiency was 98 at the 5-year stand, which decreased with increasing age to 81 at the 40-year stand. Similarly, P use efficiency at the 5-year stand was 2439 that decreased with increase in age to a minimum value of 1914 at the 40-year stand. Average P use efficiency of all stands was greater by about 25 times than that of N use efficiency.

Computation of ratios (nutrient uptake): (energy fixation efficiency) takes into account both aboveground and belowground production of plantations, and the ratios (nutrient release): (energy dissipated) are based on floor-litter and root nodule disappearance (Table 8.10). Nitrogen and P uptake per unit energy fixed remained almost similar in the younger stands and slightly increased with plantation age. Amount of nutrient released per unit energy dissipated was highest in the 5-year stand and decreased with increasing age to a minimum value in the 30-year stand.

Nitrogen distribution and flow rates in the age series of *Alnus*-cardamom plantation stands are presented in Figure 8.3a, b & c. Annual N uptake from soil in the 5-year stand was greater by 1.4 times that of 15-year stand and 3.8 times that of 40-year stand. Nitrogen accretion through fixation was highest in the 15-year stand, which was 3 times greater than that of the 5-year and 2.6 times that of the 40-year stand. About 61% of the total annual N uptake is allocated to aboveground components of *Alnus* and 15% in the cardamom in the 15-year stand. The allocation shifted to 87% in *Alnus* and just 4% in cardamom at the 40-year stand. Nitrogen exit in terms of cardamom capsule (agronomic yield) was greatest

($2.89\ kg\ ha^{-1}\ year^{-1}$) in the 15-year stand being 2.8 times higher that of the 5-year stand and 7.6 times of the 40-year stand.

Phosphorus distribution and flow rates in the components of both *Alnus* and cardamom in the age series of plantation stands are presented in Figure 8.4a, b & c. Annual P uptake from soil was highest in the 15-year stand ($10.6\ kg\ ha^{-1}\ year^{-1}$) that was 1.5 times greater than the 5-year stand and 2.8 times that of the 40-year stand. In the stands up to 15 years age, allocation of P from the annual uptake remained between 30–40% in large cardamom which decreased with increasing age to just 6% allocation by the 40 years age. At the oldest stand of 40 years, 93% of annual P uptake from soil was allocated in the aboveground components of *Alnus*. Phosphorus exit from the system in the form of agronomic yield was highest in the 15-year stand ($0.29\ kg\ ha^{-1}\ year^{-1}$), which was 2.4 times greater than the 5-year stand and 7.25 times that of the 40-year stand. Nutrient content in vegetation, litter and soil and their ratios in certain forest ecosystems of the world and a comparison of the present study are presented in Table 8.11.

8.4. Discussion

Nitrogen concentrations in different plant components of *Alnus* were higher than the respective components of cardamom. This is attributed to high rates of N_2-fixation by *Alnus* (Sharma and Ambasht 1984; Sharma *et al.* 1994). Foliar nutrient (N and P) concentrations in *Alnus* decreased consistently from the young to the older plantations. A similar trend was recorded in *Alnus rubra* by DeBell and Radwan (1984). This result suggests that the supplies of these nutrients may become limiting after certain age in the older plantation stands.

The distribution of nutrients in different components in an age series of *Alnus*-cardamom plantations depended considerably on component biomass and nutrient concentration. The standing state of nutrients in different components increased with increase in their biomass and the role of nutrient concentration was minimized. Similar report was also made by Sharma (1993) in an age series of *Alnus nepalensis* plantations, and by Rawat and Singh (1988) in *Quercus* forests in the central Himalaya. Ranges of standing states of nutrients (N 313–760 kg ha^{-1}; P 6–15 kg ha^{-1}) in the present study was compared with the range given for deciduous forests: 530–1200 kg ha^{-1} for N and 40–100 kg ha^{-1} for P (Rodin and Bazilevich 1967; Duvingnuead and Devnaeyer De-Smet 1970; Nihlgard 1972). Nitrogen standing state was within the range while P was much lower. The nutrient storage in the understorey cardamom was very high (N 2–31%; P 8–59%) and highest being at the 15-year stand. Normally, the contribution of understorey vegetation in temperate forests and plantations are below 2% (Sharma 1993; Rawat and Singh 1988; Whittaker *et al.* 1979). Substantial amount of N is extracted out from the system due to thinning of *Alnus* and extraction of fuel-wood that causes lowering of N storage in the older stands. Pressure of cattle on the older stands, overland flow and leaching of nutrients are the primary source of nutrient depletion in these stands. The higher nutrient storage in understorey cardamom of the present study is mainly attributed to the management of this cash crop. It is quite interesting that relative percentage contribution of cardamom is almost double for P compared to N.

Total annual N fixation in the monoculture stands of different ages of *Alnus nepalensis* was reported from 29–117 kg ha^{-1}, the highest recorded at the youngest stand (Sharma and Ambasht 1988). However in the present, *A. nepalensis* in combination with cardamom showed slightly higher N accretion ranging from 52–155 kg ha^{-1} year^{-1}. Seasonal N accretion in all the plantation stands showed that the highest values were recorded during the rainy season between July to September. Average annual N fixation recorded in this study (155 kg ha^{-1}) was higher than 130 kg ha^{-1} in *A. rubra* (Binkley 1981) and 117 kg ha^{-1} in *A. nepalensis* (Sharma and Ambasht 1988). Newton *et al.* (1968) reported annual N fixation as high as 320 kg ha^{-1} between 2- to 15-year-old *A. rubra* stands. Contribution of N accretion through fixation to the total uptake ranged from 30–65% and the highest percentage was recorded in 10-, 15- and 20-year old stands.

Annual input of N and P to the plantation floor through litterfall and slashed pseudo-stems of cardamom increased from the youngest stand to be highest in the 15-year stand and then decreased with increase in plantation age. The contribution of cardamom to the total annual input ranged from 17–32% for N and 17–44% for P. The concentration increased from the youngest stand to peak at the 15-year stand and then decreased with advancing age exactly following N accretion trend. This indicates that the nitrogen levels in cardamom components were also influenced by N accretion either by the element being available to in the soil or more allocation from soil uptake to cardamom, as *Alnus* did not compete for soil N. However, P contribution of cardamom was highest in the youngest stand and decreased with advancing age to a minimum value in the oldest stand.

Nutrient retranslocation of senescent *Alnus* leaf showed positive relationship in case of N and negative in P with stand age. The retranslocation of N in young *Alnus* trees was minimum because this nutrient was sufficiently available through fixation; however with advancing age the demand became more as contribution from fixation decreased that affected greater back translocation. In the case of P, its demand for growth was high in younger stands where effective retranslocation was recorded. It decreased with advancing stand age. *Alnus* showed entirely different physiological behaviour for both N and P at different stages of age governed mostly by demand and availability of these nutrients.

Nutrient use efficiency may be expected to drop as utilization of that nutrient increases because availability of some other resource (such as water, energy, or light) limits production (Melillo and Gosz 1983; Binkley *et al.* 1992a). The nutrient use efficiencies for both N and P in *A. nepalensis* pure monoculture plantations decreased with plantation age (Sharma 1993). In the case of mixture of *Alnus* and cardamom plantations in this study, the nutrient use efficiencies were generally consistent with the above hypothesis and decreased with plantation age. *Alnus*-cardamom mixed stands used P less efficiently compared to pure stands of the same species of *Alnus* (Sharma 1993). The *Alnus*-cardamom plantations also used N less efficiently compared to mixed *Alnus rubra*-conifer stands of USA. Comparison between *A. rubra* and conifers showed less efficiency in *A. rubra* than conifers (Binkley *et al.* 1992a).

Total uptake in *Alnus*-cardamom plantations was 90–239 kg ha^{-1} $year^{-1}$ for N and 3.8–10.6 kg ha^{-1} $year^{-1}$ for P, being lower for N and higher for P compared to monoculture plantations of *A. nepalensis* (Sharma 1993). Rawat and Singh (1988) estimated nutrient uptake in a Himalayan oak forest and reported 230 kg ha^{-1} $year^{-1}$ N and 13 kg ha^{-1} $year^{-1}$ P. These comparisons revealed that pure *Alnus* plantations showed higher N uptake and lower P uptake, and in the mixed stands cardamom N uptake decreased while P uptake increased. The low P uptake in pure *A. nepalensis* was attributed to a negative effect of *Alnus* on the P economy mostly by increasing soil acidity (Sharma 1993), which causes a transition of phosphate into less soluble compounds with Fe and Al (Brozek 1990; Sharma *et al.* 1997b). Furthermore, a heavy accumulation of organic matter in soils of pure *Alnus* plantation stands could have shifted P from a plant available pool to an organically bound pool (Sharma 1993). The combination of *Alnus* with cardamom is a system where N and P uptakes are balanced compared to either pure stands of N_2-fixing species or non-N_2-fixing species. Therefore, plantation systems with mixture of N_2-fixing and non-N_2-fixing species like *Alnus*-cardamom of the present study are advantageous in balancing N and P cycling.

Turnover time in standing vegetation reflects the rate of nutrient cycling, and the mean turnover time of P was lower than N. The P turnover time remained between 1 to 2 years at all the plantation age, while N increased from 2 year in youngest stand to more than 8 years in oldest stand. The N turnover of the stand was mostly affected by *Alnus* component than the cardamom. Sharma (1993) also reported lower turnover time of P than N in an age series of pure *A. nepalensis* plantations; however they were greater for both N and P than the mixed *Alnus*-cardamom plantations of the present study. The turnover time of nutrients on the plantation floor however was slightly higher for P than N. This finding suggests that P cycling in vegetation was much quicker than N in stands with mixture of N_2-fixing and non-N_2-fixing species.

Consistently high net primary production in the age series of *Alnus*-cardamom is in conformity with marked retention of nutrients by the plants over the annual cycles. Ratio of nutrient uptake and net energy fixation remained almost similar in all the ages of *Alnus*- cardamom plantations. However, N and P uptake per unit energy fixed was higher than results of the present study and the ratios increased with plantation age in monocultures of *A. nepalensis* stands (Sharma 1993).

Performance of cardamom under the influence of N_2-fixing *Alnus* in an age series of plantations with regards to nutrient use efficiencies, nutrient dynamics and cycling suggest the system to be sustainable up to 20 years, and adoption of replantation after 20 years for both *Alnus* and cardamom would be highly beneficial and sustainable ❖

Table 8.1. Per cent nitrogen (N) and phosphorus (P) concentrations in *Alnus* tree components in an age series of *Alnus*-cardamom plantation stands. Values are mean ±SE, n=3

Plant components	Nutrient	Stand age (year)					
		5	10	15	20	30	40
Tree							
Leaf	N	3.641 ±0.21	3.490 ±0.350	3.162 ±0.310	2.932 ±0.531	2.852 ±0.310	2.631 ±0.122
	P	0.205 ±0.03	0.180 ±0.08	0.170 ±0.08	0.167 ±0.04	0.162 ±0.03	0.151 ±0.016
Twig	N	0.810 ±0.02	0.780 ±0.128	0.942 ±0.110	0.703 ±0.210	0.950 ±0.036	0.847 ±0.15
	P	0.052 ±0.01	0.017 ±0.003	0.024 ±0.001	0.027 ±0.003	0.031 ±0.001	0.021 ±0.001
Catkin	N	2.430 ±0.21	2.618 ±0.14	2.655 ±0.21	2.705 ±0.120	2.645 ±0.01	2.624 ±0.02
	P	0.130 ±0.01	0.150 ±0.014	0.161 ±0.013	0.182 ±0.011	0.163 ±0.003	0.156 ±0.007
Branch	N	0.640 ±0.01	0.580 ±0.002	0.591 ±0.001	0.642 ±0.004	0.612 ±0.005	0.656 ±0.003
	P	0.004 ±0.00	0.003 ±0.0001	0.003 ±0.0002	0.006 ±0.0003	0.005 ±0.0001	0.003 ±0.0001
Bole	N	0.33 ±0.01	0.294 ±0.008	0.332 ±0.001	0.343 ±0.002	0.321 ±0.001	0.355 ±0.002
	P	0.002 ±0.00	0.003 ±0.0001	0.003 ±0.0002	0.004 ±0.0001	0.002 ±0.0001	0.003 ±0.0001
Root	N	1.20 ±0.01	1.310 ±0.001	1.415 ±0.003	1.513 ±0.032	1.210 ±0.024	1.115 ±0.036
	P	0.005 ±0.002	0.006 ±0.0001	0.007 ±0.001	0.004 ±0.002	0.005 ±0.001	0.005 ±0.0032

Table 8.2. Per cent nitrogen (N) and phosphorus (P) concentrations in plant components of cardamom in the age series of *Alnus*-cardamom plantation stands. Values are mean ± SE, n=3

Plant components	Nutrient	Stand age (year)					
		5	10	15	20	30	40
Cardamom							
Leaf	N	2.067 ±0.021	2.155 ±0.012	2.091 ±0.031	2.075 ±0.013	1.973 ±0.031	2.095 ±0.002
	P	0.115 ±0.009	0.137 ±0.007	0.158 ±0.01	0.167 ±0.02	0.139 ±0.004	0.091 ±0.006
Pseudo-stem	N	0.364 ±0.021	0.398 ±0.030	0.367 ±0.008	0.607 ±0.001	0.577 ±0.004	0.325 ±0.014
	P	0.061 ±0.001	0.080 ±0.005	0.067 ±0.003	0.077 ±0.004	0.088 ±0.006	0.032 ±0.005
Capsule	N	0.910 ±0.176	0.849 ±0.149	0.938 ±0.166	1.00 ±0.102	0.854 ±0.261	0.952 ±0.122
	P	0.107 ±0.015	0.0929 ±0.002	0.094 ±0.002	0.089 ±0.008	0.091 ±0.002	0.092 ±0.001
Rhizome	N	0.620 ±0.011	0.487 ±0.003	0.520 ±0.002	0.503 ±0.002	0.310 ±0.020	0.542 ±0.002
	P	0.002 ±0.000	0.002 ±0.000	0.003 ±0.000	0.002 ±0.000	0.004 ±0.000	0.002 ±0.000
Root	N	0.612 ±0.01	0.544 ±0.01	0.635 ±0.04	0.543 ±0.005	0.611 ±0.002	0.630 ±0.03
	P	0.089 ±0.0001	0.054 ±0.0002	0.082 ±0.005	0.083 ±0.003	0.091 ±0.004	0.092 ±0.005

Table 8.3. Standing state of nutrients (kg ha^{-1}) in different *Alnus* and cardamom components in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates (± s.e.; n = 9)

Stand age (year)	Nutrients	*Alnus*					Cardamom			Stand total
		LT	CT	BR	BO	RT	CL	PS	RR	
5	N	42.04 ±2.61	7.35 ±0.94	43.71 ±4.21	51.88 ±9.61	106.33 ±14.29	12.82 ±1.23	6.79 ±0.65	42.09 ±6.00	313
	P	2.43 ±0.14	0.39 ±0.05	0.29 ±0.03	0.28 ±0.01	0.83 ±0.06	0.94 ±0.09	1.14 ±0.11	0.14 ±0.01	6
10	N	61.94 ±2.66	11.49 ±1.66	55.66 ±7.30	66.23 ±5.77	122.93 ±5.27	26.69 ±6.16	14.85 ±3.43	65.54 ±15.09	425
	P	2.86 ±0.14	0.67 ±0.11	0.37 ±0.05	0.36 ±0.03	1.31 ±0.02	1.70 ±0.39	2.98 ±0.69	0.30 ±0.01	11
15	N	54.15 ±3.18	13.91 ±1.91	87.16 ±20.80	115.38 ±32.80	178.67 ±52.00	48.57 ±20.02	25.65 ±10.56	131.56 ±26.65	655
	P	2.56 ±0.06	0.81 ±0.12	0.59 ±0.14	0.63 ±0.18	1.61 ±0.23	3.67 ±1.51	4.68 ±1.93	0.58 ±0.12	15
20	N	44.45 ±5.32	14.81 ±2.13	112.53 ±20.77	158.18 ±29.13	242.25 ±34.64	21.98 ±2.14	19.30 ±1.89	54.27 ±3.98	668
	P	2.37 ±0.29	0.99 ±0.14	0.76 ±0.14	0.87 ±0.16	1.86 ±0.15	1.77 ±0.17	2.44 ±0.24	0.24 ±0.02	11
30	N	34.64 ±3.06	14.04 ±1.85	121.03 ±21.48	194.65 ±33.46	246.12 ±43.26	14.60 ±4.46	8.28 ±2.57	24.68 ±7.65	658
	P	1.77 ±0.16	0.85 ±0.14	0.81 ±0.15	0.97 ±0.18	1.39 ±0.19	1.01 ±0.32	1.93 ±0.38	0.18 ±0.05	9
40	N	30.88 ±0.49	13.78 ±2.46	165.57 ±44.36	264.74 ±19.00	266.09 ±54.76	6.31 ±2.02	2.86 ±0.98	9.38 ±1.01	760
	P	1.63 ±0.02	0.79 ±0.14	1.11 ±0.29	1.44 ±0.43	1.46 ±0.24	0.28 ±0.58	0.28 ±0.09	0.03 ±0.004	7

LT = leaf and twig; CT = catkin; BR = branch; BO = bole; RT = root and root nodule; CL = cardamom leaf; PS = pseudo-stem; RR = root and rhizome; N = nitrogen; P = phosphorus

Table 8.4. Annual input of nitrogen and phosphorus (kg ha^{-1}) to the stand floor through litter production in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates (± s. e.; $n = 9$)

Stand age (year)	Nutrients	*Alnus* leaf & twig	*Alnus* catkin	Cardamom leaf & pseudo-stem	Stand total
5	N	63.52±2.61	7.35±0.94	26.06±0.55	96.93
	P	2.49±0.14	0.39±0.52	2.28±0.05	5.16
10	N	75.09±2.70	11.49±1.66	27.69±2.18	114.27
	P	2.54±0.12	0.67±0.11	2.40±0.19	5.61
15	N	97.86±3.20	13.31±1.91	51.36±1.03	162.53
	P	3.96±0.10	0.81±0.12	2.58±0.52	7.35
20	N	68.53±5.32	14.81±2.13	22.11±5.05	105.45
	P	3.00±0.28	0.99±0.14	2.01±0.46	6.00
30	N	64.88±3.10	14.03±1.85	16.44±1.71	95.36
	P	3.16±0.16	0.85±0.11	1.39±0.14	5.40
40	N	36.80±0.50	13.78±2.46	11.74±0.69	62.32
	P	2.18±0.02	0.79±0.14	0.60±0.03	3.57

N = nitrogen; P = phosphorus

Table 8.5. Floor-litter biomass and nutrient content in the age series of *Alnus*-cardamom plantation stands. Values are means of three site replicates.

Stand age (year)	Floor-litter ($t\ ha^{-1}$)	Nutrients ($kg\ ha^{-1}$)	
		Nitrogen	Phosphorus
5	18.51 ±0.25	240.63 ±18.19	13.14 ±2.45
10	23.16 ±2.06	305.71 ±10.73	22.00 ±5.77
15	34.91 ±1.24	429.39 ±11.52	33.16 ±4.89
20	28.05 ±1.44	339.41 ±12.42	26.96 ±1.23
30	24.27 ±0.58	327.65 ±13.49	18.20 ±1.9
40	14.67 ±1.04	176.04 ±14.00	11.88 ±2.68

Table 8.6. Turnover rate (k) and turnover time (t, years) of nutrients on stand floor in the age series of *Alnus*-cardamom plantation stands. Values are pooled from three site replicates.

Stand age (year)	Nitrogen		Phosphorus	
	k	*t*	*k*	*t*
5	0.40	2.5	0.39	2.5
10	0.37	2.6	0.26	3.9
15	0.38	2.7	0.22	4.5
20	0.31	3.2	0.22	4.4
30	0.29	3.4	0.29	3.6
40	0.35	3.0	0.30	3.4

Table 8.7. Uptake, retention, return and standing state of nutrients in the age series of *Alnus*-cardamom plantation stands. Values are pooled from three site replicates.

Nutrients	Stand age (year)	Uptake (kg ha^{-1} year^{-1})	Return (kg ha^{-1} year^{-1})	Retention (kg ha^{-1} year^{-1})	Standing state ** (kg ha^{-1})
Nitrogen	5	171.04*	71.26	99.78	553.64
	10	202.36*	102.37	99.99	731.04
	15	238.83*	126.46	112.37	1084.44
	20	168.85*	68.93	99.92	1006.87
	30	150.47*	66.50	83.97	970.84
	40	90.12*	44.97	45.15	926.14
Phosphorus	5	6.86	3.77	3.09	19.58
	10	8.77	4.88	3.89	32.55
	15	10.60	5.56	5.04	48.29
	20	7.62	3.74	3.88	38.26
	30	6.79	3.09	3.70	27.11
	40	3.83	2.51	1.32	18.90

* Includes biological nitrogen fixation

** Includes floor litter nutrient

Table 8.8. Turnover time (year) of nutrients in the standing vegetation of *Alnus* and cardamom in the age series of *Alnus*-cardamom plantation stands. Values are pooled for three site replicates.

Stand age (year)	Nitrogen			Phosphorus		
	Alnus	Cardamom	Stand total	*Alnus*	Cardamom	Stand total
5	1.87	1.69	1.83	0.89	1.02	1.10
10	2.08	2.16	2.10	1.12	1.32	1.20
15	2.66	3.23	2.74	0.89	2.17	1.43
20	4.18	2.78	3.95	1.25	2.07	1.48
30	4.96	2.06	4.62	1.09	2.08	1.31
40	8.67	3.09	8.32	1.78	2.68	1.83

Table 8.9. Nutrient use efficiency in the age series of *Alnus*-cardamom plantation stands. Values are pooled from three site replicates.

Stand age (year)	Total net primary productivity (t ha^{-1} $year^{-1}$)	Nutrient use efficiency	
		Nitrogen	Phosphorus
5	16.73	97.81	2438.78
10	19.57	96.71	2231.47
15	22.40	93.71	2111.32
20	14.72	87.18	1934.36
30	13.06	86.79	1923.42
40	7.35	81.34	1913.84

Table 8.10. Ratios between nutrient uptake (NU) and net energy fixation (NEF), and nutrient release (NR) and energy dissipation (ED) in the age series of *Alnus*-cardamom plantation stands. NU and NR are quantified as kg ha^{-1} $year^{-1}$ and NEF and ED as kJ ha^{-1} $year^{-1}$. Values are pooled from three site replicates

Ratio	Stand age (year)	Nitrogen	Phosphorus
NU: NEF	5	0.531	0.021
	10	0.520	0.023
	15	0.538	0.024
	20	0.554	0.025
	30	0.577	0.026
	40	0.585	0.030
NR: ED	5	0.67	0.024
	10	0.52	0.022
	15	0.46	0.019
	20	0.31	0.012
	30	0.28	0.012
	40	0.37	0.013

Table 8.11. Nutrient content (kg) in vegetation (V), litter (L) and soil (S) and their ratios in certain forest ecosystems of the world.

Forest	Parameter	N	P	Ca	Mg	K	Reference
Pinus banksiana (Ontario, Canada)	V	165	14	112	18	82	Foster & Morrison (1976)
	L	328	43	500	116	524	
	S (0-30 cm)	3729	29a	118b	29b	388b	
	L/V	2	3	5	6	5	
	S/V	23	2	2	2	5	
Pine forest, Central Himalaya, India	V	1145	148	540	212	378	Chaturbedi & Singh (1987)
	L	131	11	83	20	24	
	S (0-20 cm)	3964	218	2883	319	248	
	L/V	0.11	0.07	0.15	0.09	0.06	
	S/V	3.46	1.47	5.33	1.50	0.66	
Alnus nepalensis, Eastern Himalaya	V	3516	27	758	-	1264	Sharma & Ambasht (1993)
	L	975	27	115	-	147	
	S (100 cm)	32740	811	873	-	440	
	L/V	0.28	1.0	0.15	-	0.12	
	S/V	9.3	30.0	1.15	-	0.35	
Alnus-cardamom plantations, Sikkim Himalaya	V	313-750	6.44-15.13				Present study
	L	176-149	11.88-33.20				
	S(0-30 cm)	8360-11663	2192-2554				
	L/V	0.23-0.77	1.69-2.19				
	S/V	11.98-26.71	169-355				

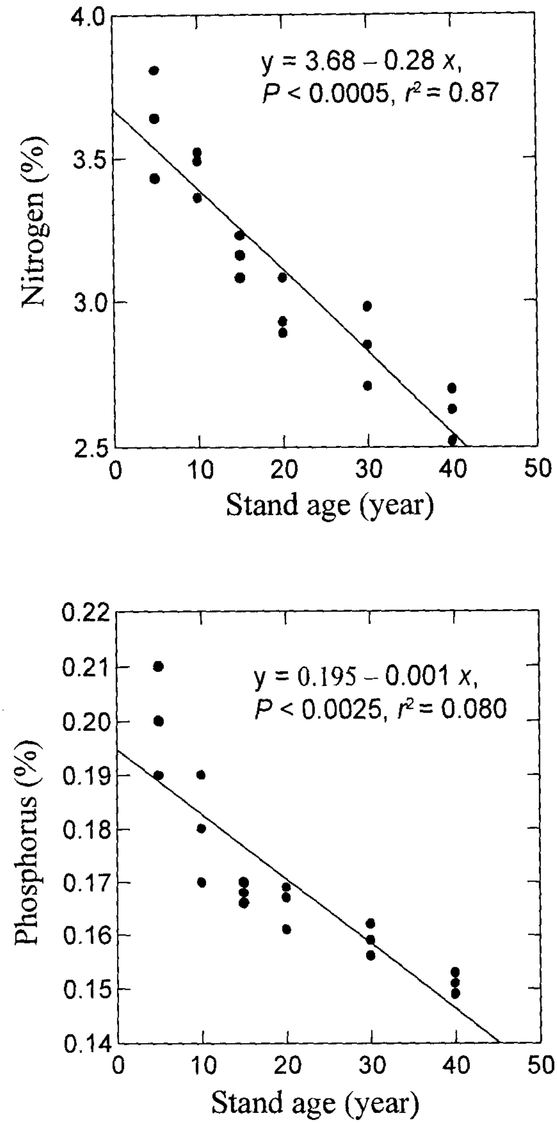


Fig. 8.1. Relationships between foliar nitrogen and phosphorus concentration of *Alnus nepalensis* with stand age in an age series of *Alnus*-cardamom plantation stands.

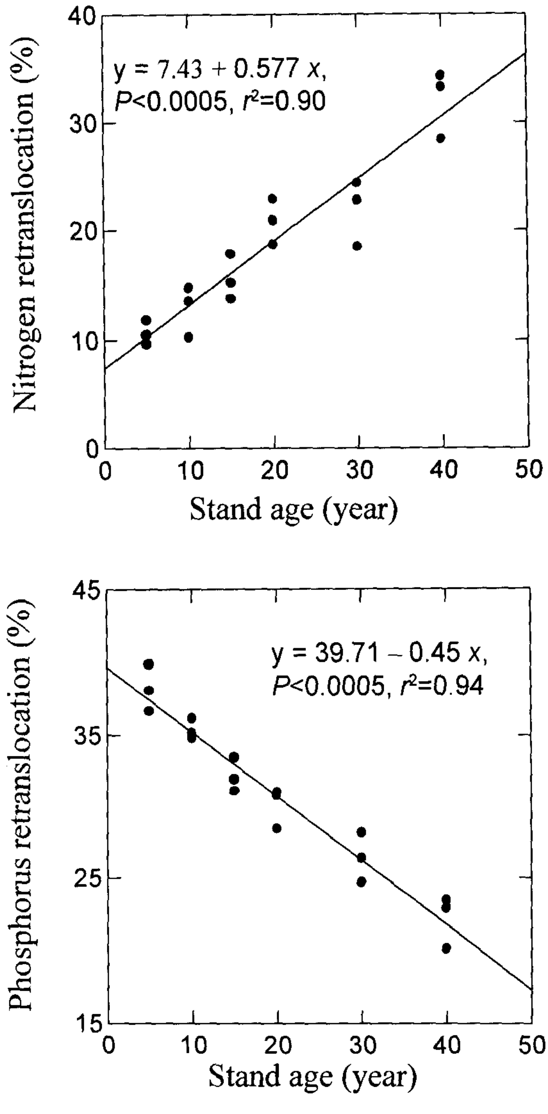
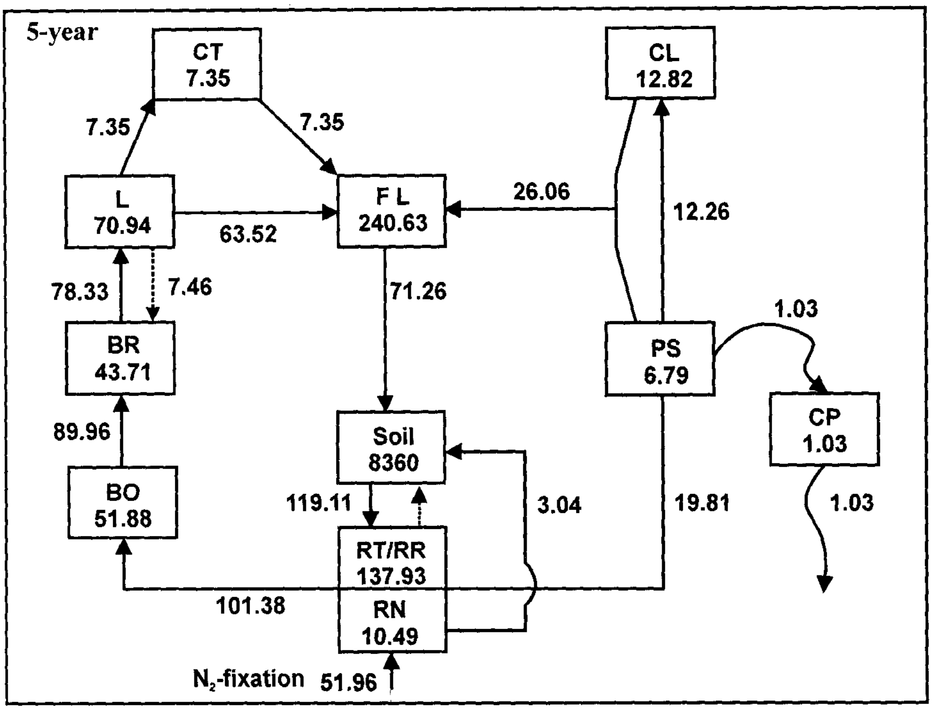


Fig. 8.2. Relationships between nitrogen and phosphorus retranslocation with stand age in the age series of *Alnus*-cardamom plantation stands.

Fig. 8.3a. D stribution of nitrogen and flow rates in the plant component of *Alnus* and cardamom in 5- and 10-year *Alnus*-carda mom plantation stands. Units are kg ha^{-1} for compartme its and kg ha^{-1} $year^{-1}$ for flows. Soil total nitrogen is presented for top 30 cm depth. Broken lines indicate re ranslocation. CT=catkin, L=leaf, BR=branch, BO=bole, R' '=root, RR=rhizome, RN=root nodule, FL=floor litter, CL=ca rdamom leaf, PS=pseudo-stem, CP=cardamom capsule


5-year
CT
7.35
7.35
7.35
CL
12.82
L
70.94
F L
240.63
26.06
12.26
63.52
78.33
7.46
71.26
1.03
BR
43.71
PS
6.79
CP
1.03
89.96
Soil
8360
BO
51.88
119.11
3.04
19.81
1.03
RT/RR
137.93
101.38
RN
10.49
N_2-fixation
51.96

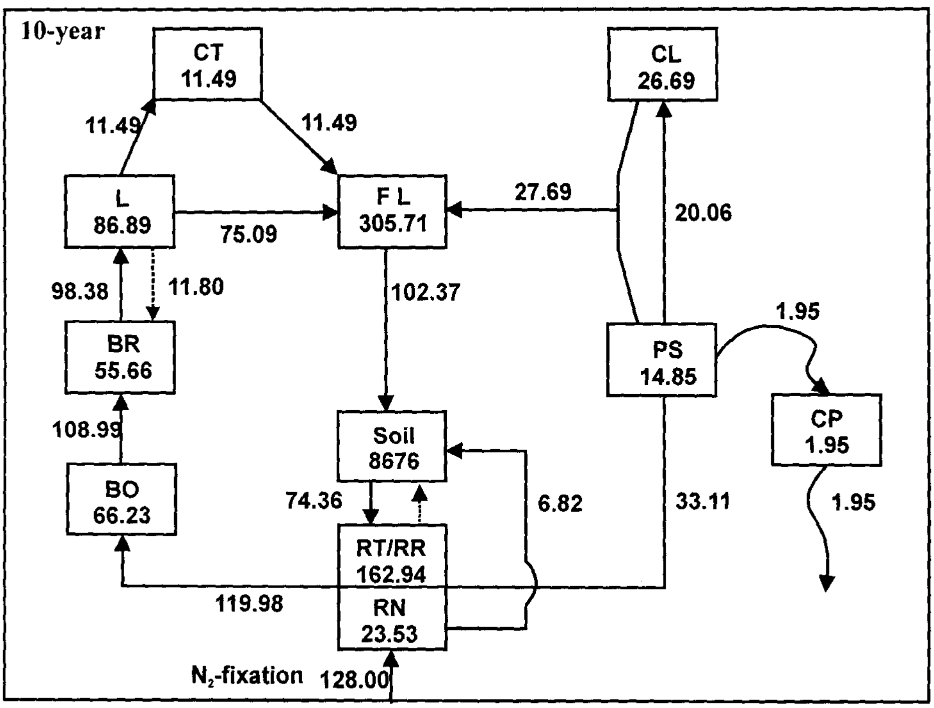
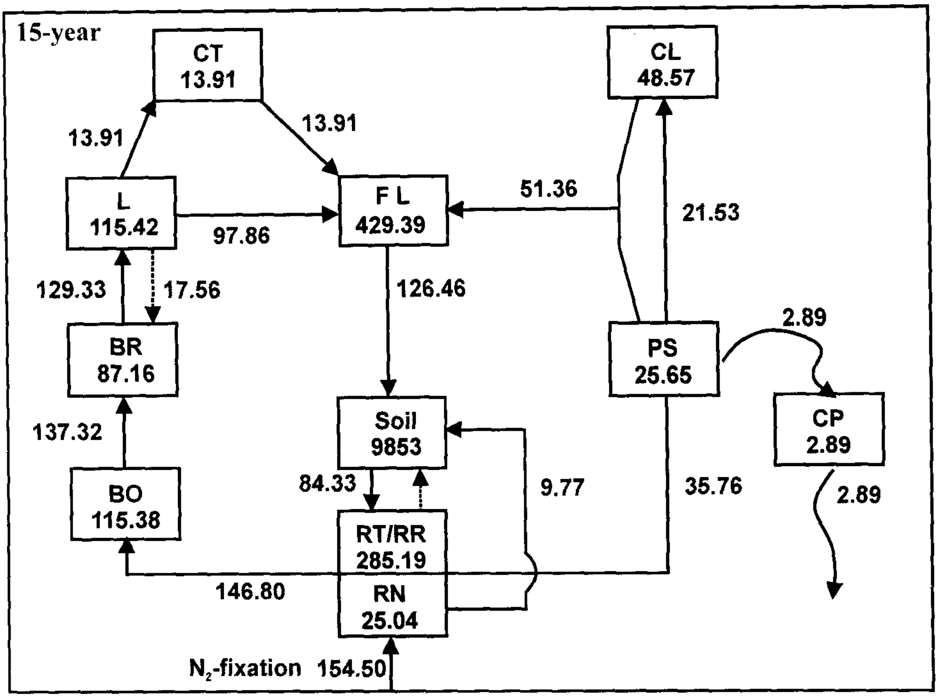

10-year
CT
11.49
11.49
11.49
CL
26.69
L
86.89
F L
305.71
27.69
20.06
75.09
98.38
11.80
102.37
1.95
BR
55.66
PS
14.85
CP
1.95
108.99
Soil
8676
BO
66.23
74.36
6.82
33.11
1.95
RT/RR
162.94
119.98
RN
23.53
N_2-fixation
128.00

Fig. 8.3b. D stribution of nitrogen and flow rates in the plant component s of *Alnus* and cardamom in 15- and 20-year *Alnus*-carda mom plantation stands. Units are kg ha^{-1} for compartme nts and kg ha^{-1} $year^{-1}$ for flows. Soil total nitrogen is presented for top 30 cm depth. Broken lines indicate re ranslocation. CT=catkin, L=leaf, BR=branch, BO=bole, R' '=root, RR=rhizome, RN=root nodule, FL=floor litter, CL=ca rdamom leaf, PS=pseudo-stem, CP=cardamom capsule


15-year
CT 13.91
13.91
13.91
CL 48.57
L 115.42
97.86
F L 429.39
51.36
21.53
129.33
17.56
126.46
2.89
BR 87.16
PS 25.65
CP 2.89
137.32
Soil 9853
BO 115.38
84.33
9.77
35.76
2.89
RT/RR 285.19
146.80
RN 25.04
N2-fixation 154.50

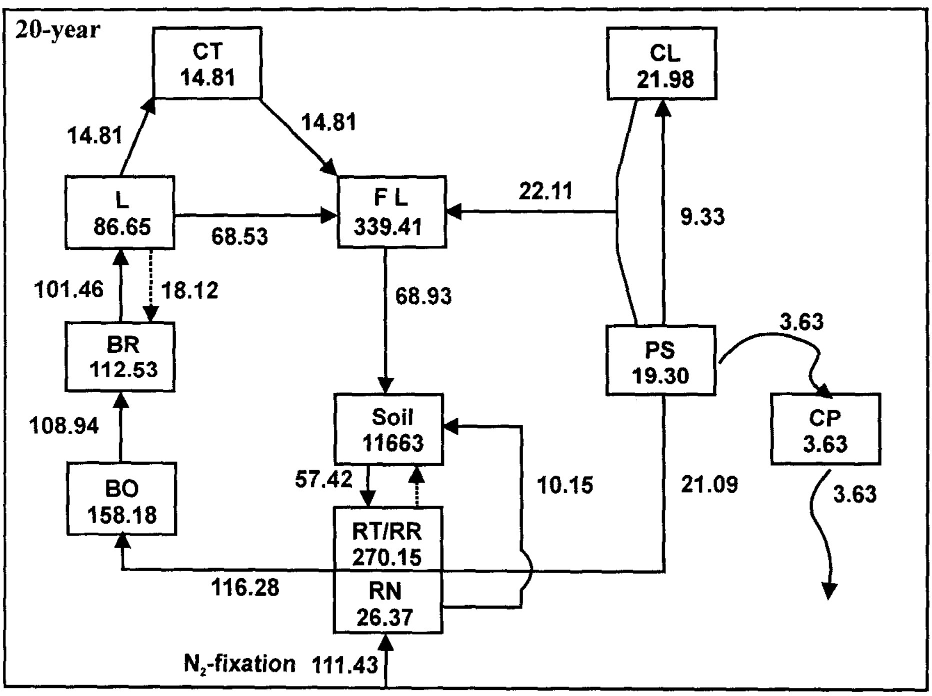
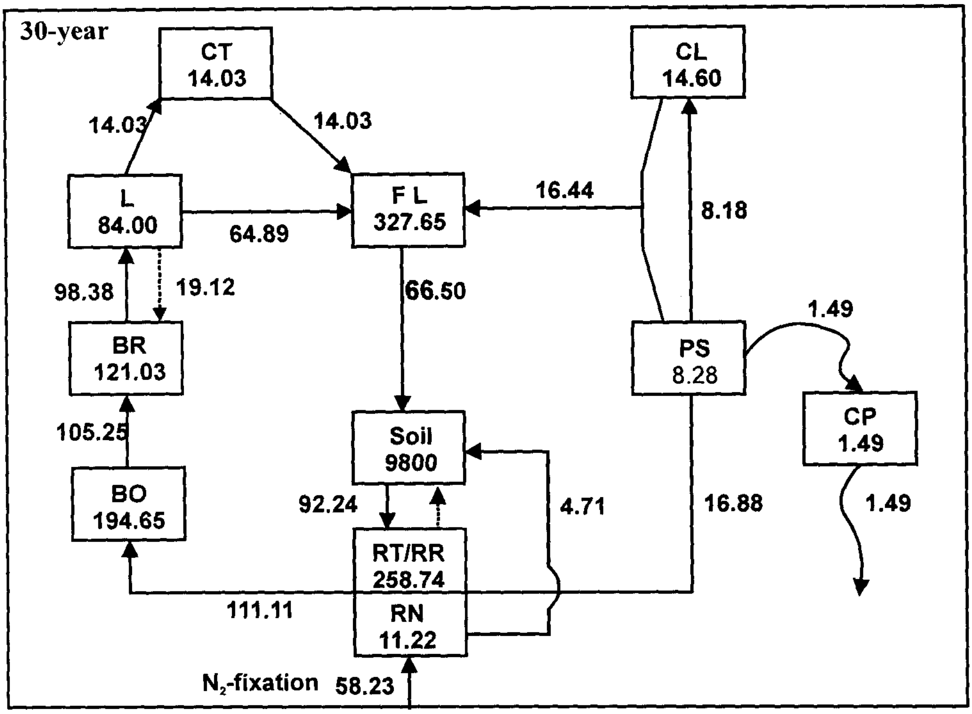

20-year
CT 14.81
14.81
14.81
CL 21.98
L 86.65
68.53
F L 339.41
22.11
9.33
101.46
18.12
68.93
3.63
BR 112.53
PS 19.30
CP 3.63
108.94
Soil 11663
BO 158.18
57.42
10.15
21.09
3.63
RT/RR 270.15
116.28
RN 26.37
N2-fixation 111.43

Fig. 8.3c. Distribution of nitrogen and flow rates in the plant components of *Alnus* and cardamom in 30- and 40-year *Alnus*-cardamom plantation stands. Units are kg ha^{-1} for compartments and kg ha^{-1} $year^{-1}$ for flows. Soil total nitrogen is presented for top 30 cm depth. Broken lines indicate retranslocation. CT=catkin, L=leaf, BR=branch, BO=bole, RT=root, RR=rhizome, RN=root nodule, FL=floor litter, CL=cardamom leaf, PS=pseudo-stem, CP=cardamom capsule


30-year
CT
14.03
CL
14.60
14.03
14.03
L
84.00
F L
327.65
16.44
8.18
64.89
98.38
19.12
66.50
1.49
BR
121.03
PS
8.28
CP
1.49
105.25
Soil
9800
BO
194.65
92.24
4.71
16.88
1.49
RT/RR
258.74
111.11
RN
11.22
N₂-fixation 58.23

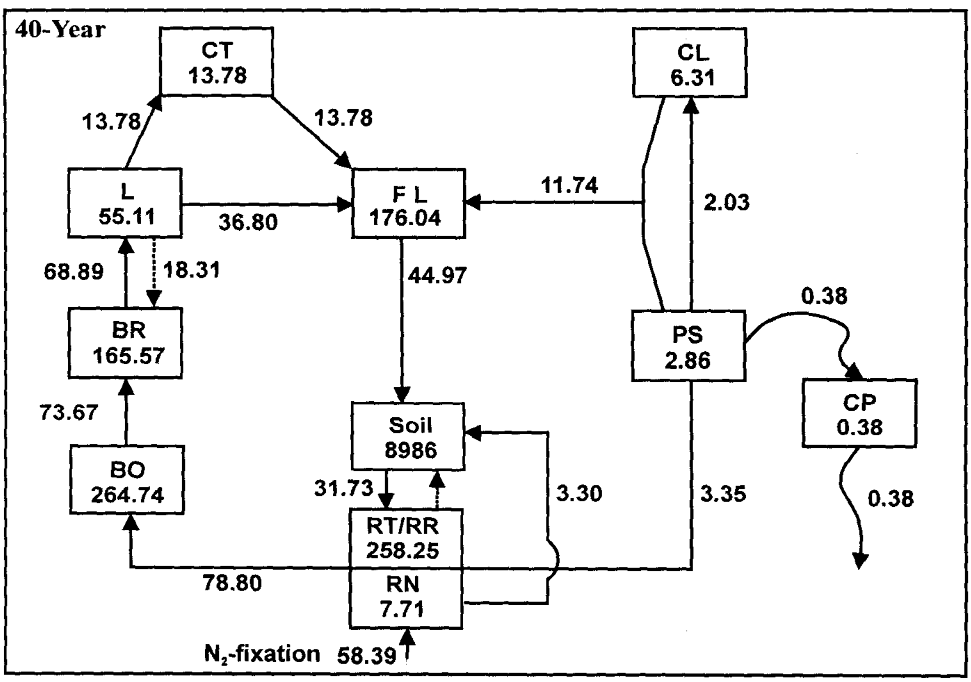
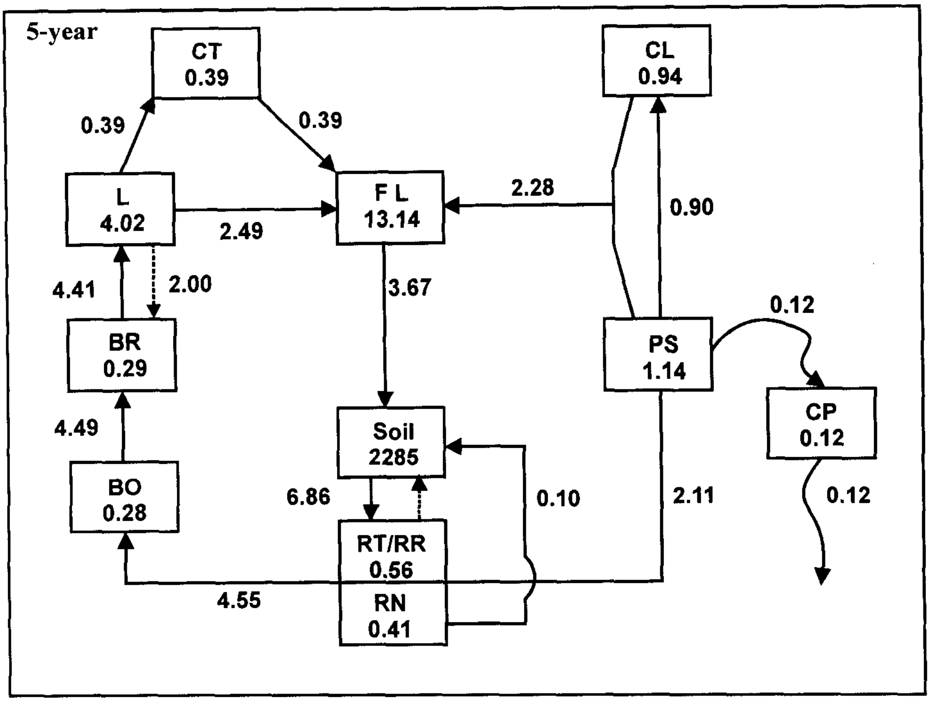

40-Year
CT
13.78
CL
6.31
13.78
13.78
L
55.11
F L
176.04
11.74
2.03
36.80
68.89
18.31
44.97
0.38
BR
165.57
PS
2.86
CP
0.38
73.67
Soil
8986
BO
264.74
31.73
3.30
3.35
0.38
RT/RR
258.25
78.80
RN
7.71
N₂-fixation 58.39

Fig. 8.4a. Distribution of phosphorus and flow rates in the plant components of *Alnus* and cardamom in 5- and 10-year *Alnus*-cardamom plantations stands. Units are kg ha^{-1} for compartments and kg ha^{-1} $year^{-1}$ for flows. Soil total phosphorus is presented for top 30 cm depth. Broken lines indicate retranslocation. CT=catkin, L=leaf, BR=branch, BO=bole, RT=root, RR=rhizome, RN=root nodule, FL=floor litter, CL=cardamom leaf, PS=pseudo-stem, CP=cardamom capsule


5-year
CT
0.39
CL
0.94
0.39
0.39
L
4.02
F L
13.14
2.28
0.90
2.49
4.41
2.00
3.67
0.12
BR
0.29
PS
1.14
CP
0.12
4.49
Soil
2285
BO
0.28
6.86
0.10
2.11
0.12
RT/RR
0.56
4.55
RN
0.41

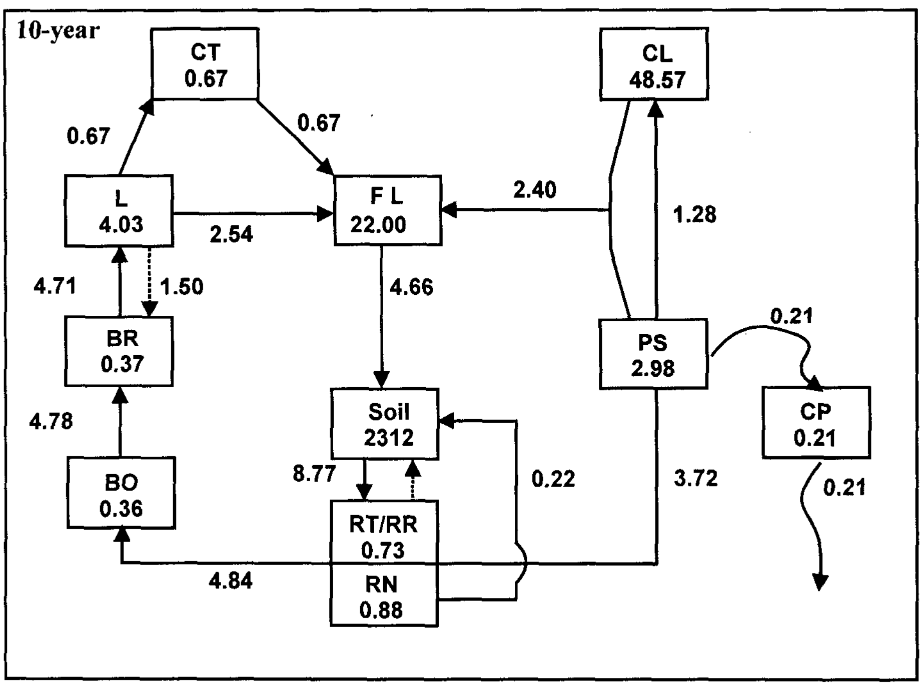
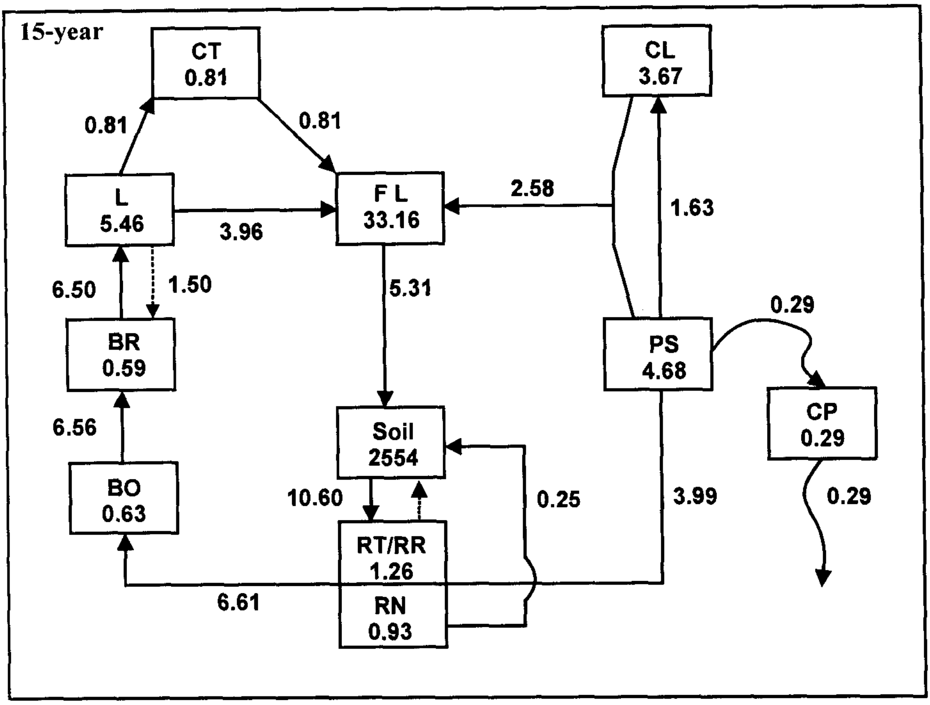

10-year
CT
0.67
CL
48.57
0.67
0.67
L
4.03
F L
22.00
2.40
1.28
2.54
4.71
1.50
4.66
0.21
BR
0.37
PS
2.98
CP
0.21
4.78
Soil
2312
8.77
0.22
3.72
0.21
BO
0.36
RT/RR
0.73
4.84
RN
0.88

Fig. 8.4b. Distribution of phosphorus and flow rates in the plant components of *Alnus* and cardamom in 15- and 20-year *Alnus*-cardamom plantation stands. Units are kg ha^{-1} for compartments and kg ha^{-1} $year^{-1}$ for flows. Soil total phosphorus is presented for top 30 cm depth. Broken lines indicate retranslocation. CT=catkin, L=leaf, BR=branch, BO=bole, RT=root, RR=rhizome, RN=root nodule, FL=floor litter, CL=cardamom leaf, PS=pseudo-stem, CP=cardamom capsule


15-year
CT
0.81
CL
3.67
0.81
0.81
L
5.46
F L
33.16
2.58
1.63
3.96
6.50
1.50
5.31
0.29
BR
0.59
PS
4.68
CP
0.29
6.56
Soil
2554
BO
0.63
10.60
0.25
3.99
0.29
RT/RR
1.26
6.61
RN
0.93

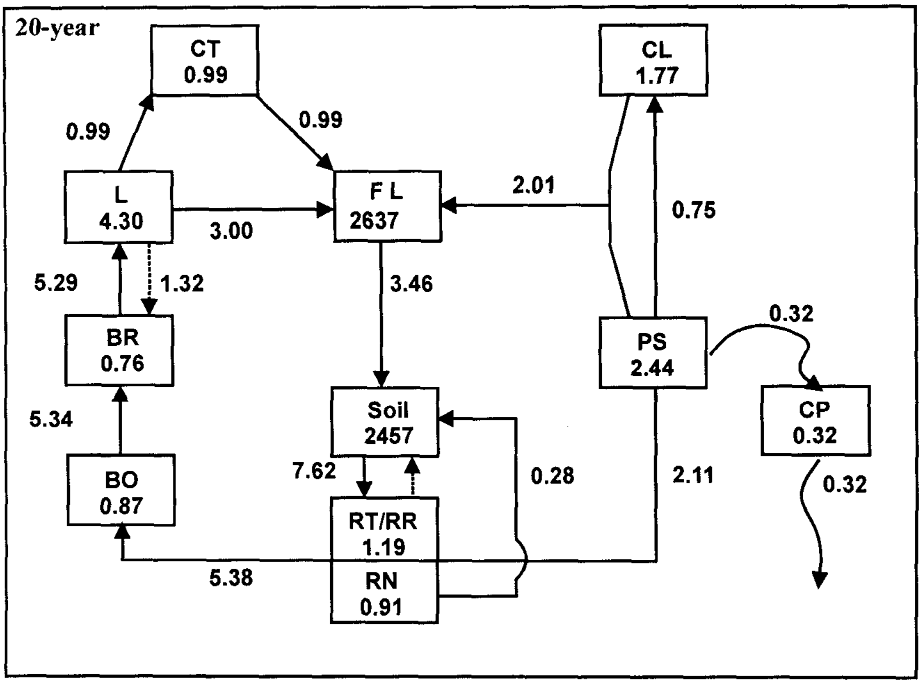
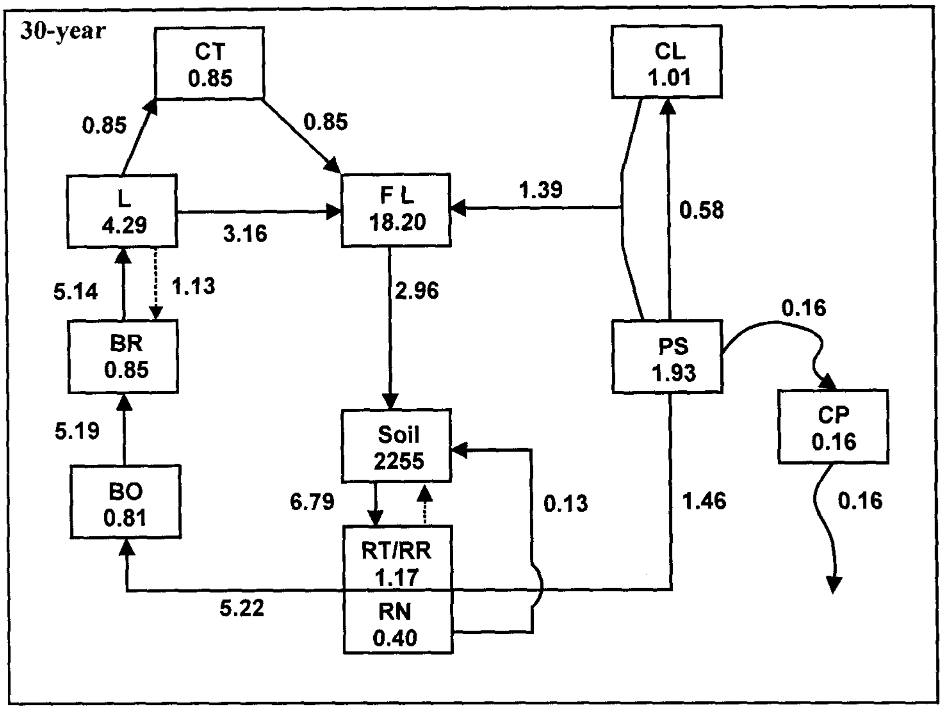
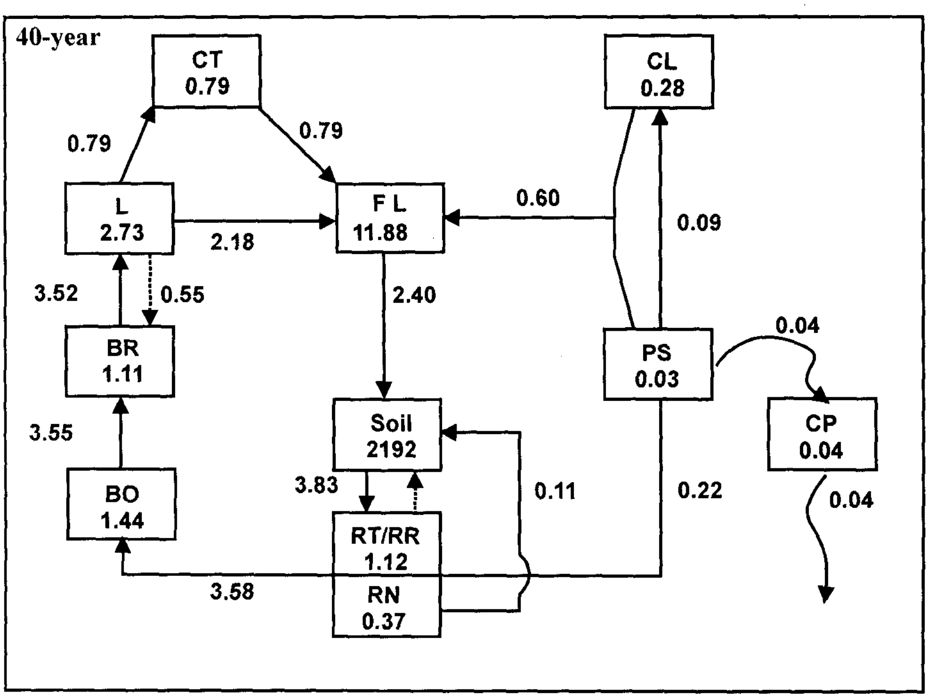

20-year
CT
0.99
CL
1.77
0.99
0.99
L
4.30
F L
2637
2.01
0.75
3.00
5.29
1.32
3.46
0.32
BR
0.76
PS
2.44
CP
0.32
5.34
Soil
2457
BO
0.87
7.62
0.28
2.11
0.32
RT/RR
1.19
5.38
RN
0.91

Fig. 8.4c. D stribution of phosphorus and flow rates in the plant comp onents of *Alnus* and cardamom in 30- and 40-year *Alnus*- ardamom plantations stands. Units are kg ha^{-1} for compar ments and kg ha^{-1} $year^{-1}$ for flows. Soil total phosphorus is presented for top 30 cm depth. Broken lines indicate re ranslocation. CT=catkin, L=leaf, BR=branch, BO=bole, R' =root, RR=rhizome, RN=root nodule, FL=floor litter, CL=c rdamom leaf, PS=pseudo-stem, CP=cardamom capsule


30-year
CT
0.85
CL
1.01
0.85
0.85
L
4.29
F L
18.20
1.39
0.58
3.16
5.14
1.13
2.96
0.16
BR
0.85
PS
1.93
CP
0.16
5.19
Soil
2255
BO
0.81
6.79
0.13
1.46
0.16
RT/RR
1.17
5.22
RN
0.40


40-year
CT
0.79
CL
0.28
0.79
0.79
L
2.73
F L
11.88
0.60
0.09
2.18
3.52
0.55
2.40
0.04
BR
1.11
PS
0.03
CP
0.04
3.55
Soil
2192
BO
1.44
3.83
0.11
0.22
0.04
RT/RR
1.12
3.58
RN
0.37