Agroforestry Systems 27: 293–306, 1994.

Dry matter production and nutrient cycling in agroforestry systems of cardamom grown under *Alnus* and natural forest

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Key words: *Alnus nepalensis* D. Don, *Amomum subulatum* Roxb., agronomic yield, net primary productivity, nutrient back translocation, nutrient use efficiency, nutrient cycling

Abstract. A study on dry matter production and nutrient cycling in agroforestry systems of cardamom grown under N_2-fixing *Alnus* and mixed tree species (non-N_2-fixing) was carried out in the Sikkim Himalaya. The stand total biomass, and tiller number, basal area and biomass of cardamom crop was much higher under the influence of *Alnus*. Annual net primary productivity of *Alnus* trees was slightly higher than mixed tree species in spite of lower stand density of *Alnus*. The agronomic yield of cardamom increased by 2.2 times under the canopy of *Alnus*. Litter production and its disappearance rates were also higher in the *Alnus*-cardamom stand. Nitrogen and phosphorus concentrations of different components of *Alnus* were higher than those of mixed tree species, whereas their back translocation from leaf before abscission was lower in *Alnus*. The cardamom based agroforestry system under the influence of *Alnus* was more productive with faster rates of nutrient cycling. The poor nutrient conservation and low nutrient use efficiency of *Alnus*, and malleability of nutrient cycling under its influence make it an excellent association which promotes higher availability and faster cycling of nutrients.

Introduction

Large cardamom (*Amomum subulatum*) is the most important perennial cash crop of the Sikkim Himalayan region which is cultivated in 26000 ha of Sikkim and Darjeeling between elevation 600–2000 m. Annual agronomic production of the crop from this region amounts to 4 million kg fetching cash equivalent to about 8 million US$ in 1993, out of which 85% are produced from Sikkim and remaining from the hills of Darjeeling [Adhikary et al., 1993]. The capsule (fruit) is used as spice/condiment and contains about 3% essential oil rich in cineole [Gupta et al., 1984]. This crop is a native of the Sikkim Himalaya and occurrence of five species of wild cardamom (*A. linguiforme, A. kingii, A. aromaticum, A. corynostachyum and A. dealbatum*) is recorded in the region. The aboriginal inhabitant of Sikkim, Lepchas, collected capsules of cardamom from natural forests from time immemorial but later on these forests passed into village ownerships and the cardamom was domesticated. However, 1316 ha of reserve forest in Sikkim is still used for under canopy cardamom cultivation on lease to farmers with no rights of cutting the trees.

The cardamom is cultivated usually on steep hill slopes under tree cover either in natural forest or plantations which forms an age old agroforestry system in the region [Singh et al., 1989]. It is a shade loving plant and requires high moisture and is usually cultivated in areas where mean annual rainfall varies between 1500–3500 mm. New plantations and large patches of cardamom-based agroforestry systems have been recently converted into monocultures of *Alnus nepalensis* as shade trees.

Roots of *Alnus* species are nodulated with *Frankia* as an endophyte, and are efficient in biological N_2 fixation [Becking, 1977; Johnsrud, 1978; Akkermans and Van Dijk, 1981; Sharma and Ambasht, 1984]. Studies have been carried out on biomass production, nutrient dynamics, nitrogen fixation and its accretion in age series of monocultures of *A. nepalensis* in the region [Sharma, 1988; Sharma and Ambasht, 1986, 1987, 1991]. Monoculture plantations of age series of *A. nepalensis* are known to fix 29 to 117 kg N/ha/year [Sharma and Ambasht, 1988]. However, there is no information on the biogeochemical effects of *A. nepalensis* in cardamom-based agroforestry system. Therefore, this study was planned to (i) examine the influences of *Alnus* on stand productivity and agronomic yield of cardamom with respect to mixed tree species; (ii) characterize within-system nitrogen and phosphorus fluxes and removal from the system through agronomic yield; and (iii) examine the influences of *Alnus* on the nutrient use efficiencies.

Study sites

Location and climate

The cardamom-based agroforestry systems under investigation are located within the Mamlay watershed (27°10′8″–27°14′6″ N and 88°19′53″–88°24′43″ E) in the south district of Sikkim in the eastern Himalaya. The Mamlay watershed covers a wide range of elevations from 300–2650 m with an area of 3009 ha. It is an agrarian watershed with 62% area under agriculture land use with more than 80% of total population engaged in farming [Sharma et al., 1992]. The watershed area is geologically typified by folded structure and varied lithology with older rocks occupying the upper structural levels.

The cardamom is a perennial crop and cultivated in temperate zone of the watershed in about 104 ha land area. The selected agroforestry site (elevation 1600–1700 m) for the study is located at Dandakharka. The climate of the site is temperate, and the maximum and minimum temperatures were 25 °C and 2 °C, respectively in 1992. The annual precipitation at the site was 2250 mm in 1992. The selected stands ocçupy sloping topography (20–25° slope) and the aspect is north-west.

Agroforestry systems

The cardamom-based agroforestry systems for this study were selected at Dandakharka of the Mamlay watershed. One plot was selected with pure *A. nepalensis* tree cover and it is referred as the *Alnus*-cardamom stand. The second plot was selected adjacent to the first plot with mixed species of natural tree cover, referred to as the forest-cardamom stand. None of the mixed species in the forest-cardamom stand had symbiotic association for N_2-fixation whereas in the *Alnus*-cardamom stand *A. nepalensis* is an efficient nitrogen fixer [Sharma and Ambasht, 1984]. The mixed tree species in the forest-cardamom stand was kept intact and the ground was cleared, floor litter and slashed ground vegetation were burnt, followed by plantation of cardamom using split rhizome in 1988. In contrast, the *Alnus*-cardamom stand which was under natural forest was completely cleared, floor litter and slashed plants were burnt, and then planted *A. nepalensis* in 1986 followed by planting of cardamom using split rhizome in 1988. Split rhizome of the same stock was planted in equal density in both the stands. The age of cardamom is same in both the stands and was 5–6 years in 1992–93. Normally at this age cardamom attains its peak yield and continues to produce more or less at the same rate up to 15 years after which yield drops sharply. Mixed tree species of the forest-cardamom stand comprised of *Acer oblongum, Casearia glomerata, Engelhardtia acerifolia, Eurya acuminata, Leucosceptrum canum, Litsaea salicifolia, Lyonia ovalifolia, Maesa chisia, Nyssa sessiliflora, Osbeckia paniculata, Prunus napaulensis, Symplocos theifolia, Toona ciliata* and *Viburnum cordifolium*.

Methods

Keeping in view the homogeneity of the stands, a sample area of 20 × 30 m was marked in each of the *Alnus*-cardamom and forest-cardamom agroforestry systems. Growth estimations, litterfall, decomposition, soil sampling for chemical analysis, agronomic yield and nutrient flux studies were carried out in these sample areas. All the trees in both the sample areas were marked in February 1992. Heights of all the trees in the sample areas were measured using bamboo sticks. The volume of the standing tree bole and branches was measured, and wood biomass of each tree was estimated as a product of the volume and the specific wood density [Ruark et al., 1987; Sundriyal et al., 1994a]. Leaf and twig was plucked from different sizes of branches and estimated their dry weights, and biomass for each tree was extrapolated by recording size and number of branches per tree. Major roots of *A. nepalensis* and mixed tree species of different sizes were excavated from current year stumps of adjoining plantations and estimated the dry weights. Samples of each component were oven dried at 80 °C to constant weight for determining fresh weight to dry weight ratios.

Allometric relationships of component biomass on tree dimensions for *A. nepalensis* and mixed tree species were developed. The dbh and heights of the same trees from both the stands were measured again in February 1993. Mean annual increments of components of the individuals in the sample areas were obtained by dbh and height increment measurements and by using regression equations. The relationships between the actual estimated and predicted component biomass for *A. nepalensis* and mixed tree species of the sample areas were found to be highly significant. The net change in the component biomass yielded annual biomass accumulation, and the sum of the different components gave net biomass production of the tree strata. Monthly tree litterfall estimations were carried out for a 2-year period (1992 and 1993) using three litter traps of 1 m^2 collecting area in each stand. The monthly litterfall data was pooled for annual values. Floor litter was randomly sampled in triplicate in an area of 1 m^2 from each stand in December and extrapolated to stand values.

In the sample area of each stand a total number of cardamom bush was recorded. Average number of tillers per bush was calculated using data of 20 bushes for each stand. Total tillers for the stand was extrapolated using average number of tillers per bush and total number of bush as per stand. About 240 tillers from *Alnus*-cardamom and 140 tillers from the forest-cardamom stand 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 in each stand was recorded in December 1992 after the harvest and again in October 1993 before the harvest. The difference between biomass values of October 1993 and December 1992 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 in October 1993 and by multiplying with mean capsule weight per tiller. After the harvest of capsule, 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.

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 and nutrient release on unit area basis were calculated.

Soil samples of 0–15 and 15–30 cm depths from 0.5, 1.0 and 1.5 m from base of the trees were collected in replicates ($n = 3$) in autumn, winter, spring and rainy seasons from both the stands. Soil total nitrogen was estimated using modified Kjeldahl method [Anderson and Ingram, 1989]; and inorganic phosphorus by chloromolybdophosphoric blue colour method [Jackson, 1973]. The amounts of total nitrogen and inorganic phosphorus in each horizon (0–15 and 15–30 cm) of soil were estimated from bulk density, soil volume and nutrient concentration values. The amounts of nutrients estimated in both the horizons were summed to obtain total content down to 30 cm depth.

Plant samples were dry ashed and estimated phosphorus using sulpho-molybdophosphoric blue colour method [Jackson, 1973]. Total nitrogen was estimated by modified Kjeldahl method [Anderson and Ingram, 1989]. The nutrient contents of tree and cardamom components were computed by multiplying component biomass with respective nutrient concentration. Nutrient flow from leaf and twig and cardamom to floor was estimated through litterfall, cardamom slashed residues and their nutrient concentration estimations. The mean nutrient content of floor litter was estimated by analyzing samples in different layers at three random (1 m^2) areas in each stand. The sum of nutrient contents of tree, cardamom crop and floor litter represented standing states of a stand. Annual nutrient uptake is the sum of the production of nutrients in all components. Nutrient retention is the difference between total annual uptake and return through decomposition of the floor litter.

Results

Density and basal area of trees were 517 trees/ha and 5.6 m^2/ha, and 850 trees/ha and 6.3 m^2/ha, respectively in the *Alnus*-cardamom and forest-cardamom agroforestry stands. The cardamom of the same stock of split rhizomes were transplanted in equal density in both the stands in 1988 but after nearly 6 years the tiller number (96400/ha) and basal area (22.5 m^2/ha) in the *Alnus*-cardamom stand were 2.26 times higher than the forest-cardamom stand.

Total biomass was 28% higher in the *Alnus*-cardamom stand, and tree biomass slightly higher for *Alnus* despite its lower stand density (Table 1). The contribution of cardamom biomass to stand total biomass was 34% in *Alnus*-cardamom and 18% in the forest-cardamom stand. Contribution of *Alnus* and cardamom was about 50% each to the annual net primary productivity of the *Alnus*-cardamom stand, whereas it was 70% for mixed tree species and 30% for cardamom in the forest-cardamom stand. The stand net primary productivity was higher by 3342 kg/ha/year in *Alnus*-cardamom than the forest-cardamom stand (Table 1). Annual net primary productivity of the stand with mixed tree species was only about 69% to that of the *Alnus*-cardamom stand. Annual contribution of major root production in the *Alnus*-cardamom stand was 1.24 times than in the forest-cardamom stand. Agronomic yield of the cardamom crop was however much higher (2.22 times) in *Alnus*-cardamom than the forest-cardamom stand (Fig. 1). Actual annual cash income from cardamom in the *Alnus*-cardamom agroforestry with the current year prices was equivalent to 908 US$ per hectare as against just 410 US$ in forest-cardamom.

Contribution of *Alnus* litter was 39% and cardamom 61% to the stand total annual litter flow to floor in the *Alnus*-cardamom system. The 57% of annual litter production is decomposed while 43% accumulated on the floor. In contrary, mixed tree species litter contributed 64% and just 36% by cardamom

Table 1. Biomass and productivity (1992–93) of components in temperate cardamom based agroforestry systems of the Mamlay watershed.

Agroforestry systems	Components	Biomass (kg/ha)	Productivity (kg/ha/year)
Alnus-cardamom	Tree (*Alnus*)		
	Bole	9475	1515
	Branch	3199	484
	Leaf and twig	1674	2851*
	Root	4414	592
	Tree total	18762	5442
	Cardamom		
	Leaf	1493	1004
	Pseudo stem	5082	3415
	Root	2631	528
	Capsule	454	454
	Cardamom total	9660	5401
	Stand total	28422	10843
Forest-cardamom	Tree (Mix subsp.)		
	Bole	10712	1576
	Branch	2543	244
	Leaf and twig	1212	2905*
	Root	3874	489
	Tree total	18341	5214
	Cardamom		
	Leaf	661	453
	Pseudo stem	1925	1216
	Root	1105	413
	Capsule	205	205
	Cardamom total	3896	2287
	Stand total	22237	7501

* Tree leaf and twig production estimated on standing trees was corrected using litterfall data.

to the stand total annual litter production in the other stand. The rate of accumulation of litter on the floor was 49% in the forest-cardamom stand (Fig. 1). The litter production and its disappearance rates were respectively 1.59 and 1.79 times higher in *Alnus*-cardamom than the forest-cardamom stand.

Nitrogen and phosphorus concentrations of different plant components of *Alnus* tree were higher than mixed tree species particularly in the leaf and twig and boles (Table 2). Nitrogen (1.14 times) and phosphorus (1.13 times) in cardamom leaf was higher under forest than *Alnus* cover, whereas they were higher in pseudo stem and roots of cardamom in *Alnus* stand. There was not much difference in nitrogen and phosphorus concentrations of capsules of large cardamom of the two stands.

Nitrogen and phosphorus concentrations of intact leaf and freshly fallen

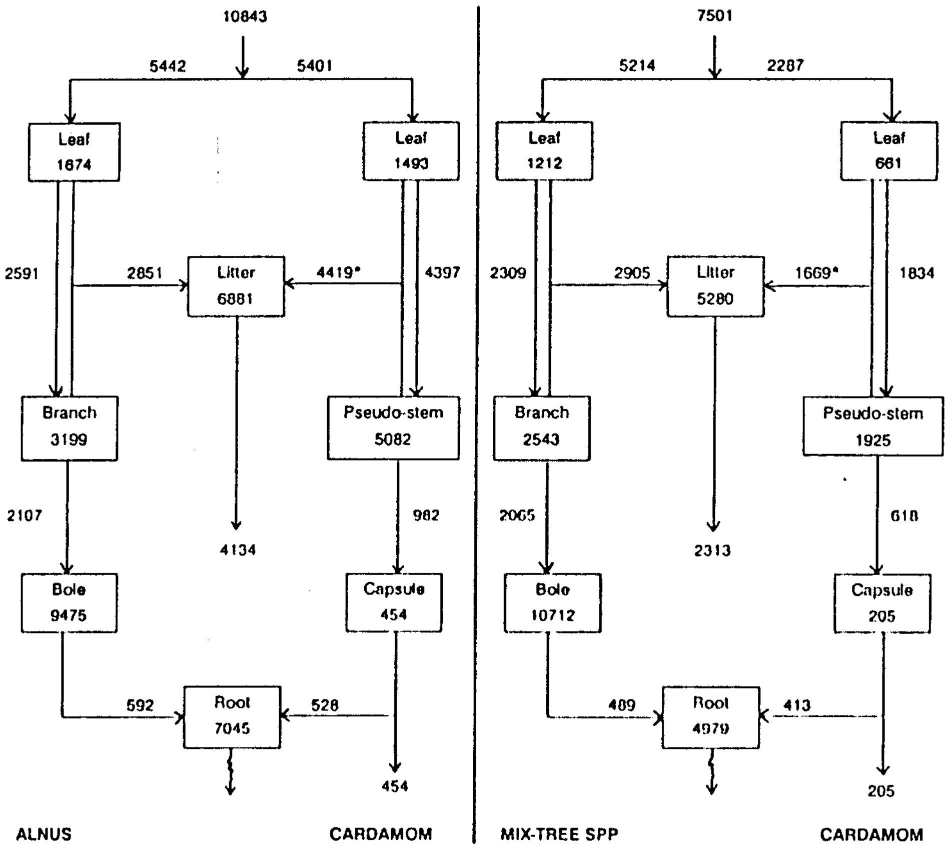

Fig. 1. Compartment model showing distribution of dry matter biomass, net primary production, litter disappearance rate and cardamom capsule harvest in *Alnus*-cardamom and forest-cardamom agroforestry systems in the Mamlay watershed. Units are kg/ha for compartments and kg/ha/year for flows. * Slashed those tillers which fruited in the current year after the harvest.

leaf of *Alnus* and mixed tree species were estimated and given in Table 3. Back translocation of nitrogen was 3.9% and phosphorus 22.6% in *Alnus* leaf while it was 17.5% nitrogen and 31.4% phosphorus in mixed tree species (Table 3). Absolute amounts of nitrogen and phosphorus back tanslocations were respectively 2.3 and 1.2 times higher in mixed tree species of the forest-cardamom stand than *Alnus* of the *Alnus*-cardamom stand (Figs. 2 and 3).

Soil total nitrogen level up to 30 cm depth of the forest-cardamom stand was 1.19 times higher than the *Alnus*-cardamom stand (Fig. 2). The annual retention of nitrogen in plant components and litter was not much different in both the *Alnus*-cardamom (56.1 kg/ha/year) and forest-cardamom (49.6 kg/ha/year) stands. Annual uptake, standing state, return to soil and exit of

Table 2. Nitrogen and phosphorus concentrations in different plant components of temperate cardamom-based agroforestry systems in the Mamlay watershed. Values are mean ± 1SE (n = 10).

Agroforestry systems	Components	Nitrogen (%)	Phosphorus (%)
Alnus-cardamom	Tree (*Alnus*)		
	Bole	0.74 ± 0.03	0.051 ± 0.011
	Branch	1.03 ± 0.07	0.065 ± 0.016
	Leaf and twig	2.93 ± 0.12	0.190 ± 0.014
	Root	0.91 ± 0.08	0.090 ± 0.012
	Cardamom		
	Leaf	1.45 ± 0.11	0.126 ± 0.008
	Pseudo stem	0.51 ± 0.06	0.109 ± 0.014
	Root	0.51 ± 0.08	0.085 ± 0.011
	Capsule	0.89 ± 0.02	0.155 ± 0.006
Forest-cardamom	Tree (Mix subsp.)		
	Bole	0.43 ± 0.05	0.038 ± 0.006
	Branch	0.73 ± 0.09	0.064 ± 0.014
	Leaf and twig	1.74 ± 0.13	0.115 ± 0.016
	Root	0.61 ± 0.04	0.050 ± 0.009
	Cardamom		
	Leaf	2.04 ± 0.15	0.143 ± 0.016
	Pseudo stem	0.45 ± 0.06	0.073 ± 0.012
	Root	0.48 ± 0.06	0.075 ± 0.007
	Capsule	0.87 ± 0.04	0.161 ± 0.011

Table 3. Nitrogen and phosphorus concentration (mg/g) of intact and freshly fallen leaf, and back translocation (%) of tree species from temperate agroforestry systems in the Mamlay watershed. Concentration values are mean (n = 10) ± 1SE.

Agroforestry systems	Species	Leaf type/translocation	Nitrogen	Phosphorus
Alnus-cardamom	*Alnus*	Intact leaf	26.0 ± 0.69	1.68 ± 0.16
		Freshly fallen leaf	25.0 ± 1.37	1.30 ± 0.18
		Black translocation	3.85	22.62
Forest-cardamon	Mixed subsp.	Intact leaf	18.3 ± 0.38	1.53 ± 0.12
		Freshly fallen leaf	15.1 ± 0.39	1.05 ± 0.09
		Back translocation	17.49	31.37

nitrogen from the systems were, respectively, 1.79, 1.92, 2.86 and 2.27 times higher in *Alnus*-cardamom than the forest-cardamom stand.

Soil inorganic phosphorus up to the 30 cm depth was higher in *Alnus*-cardamom than the forest-cardamom stand (Fig. 3). Total annual phosphorus uptake, standing state, return to soil and exit from the systems were, respec-

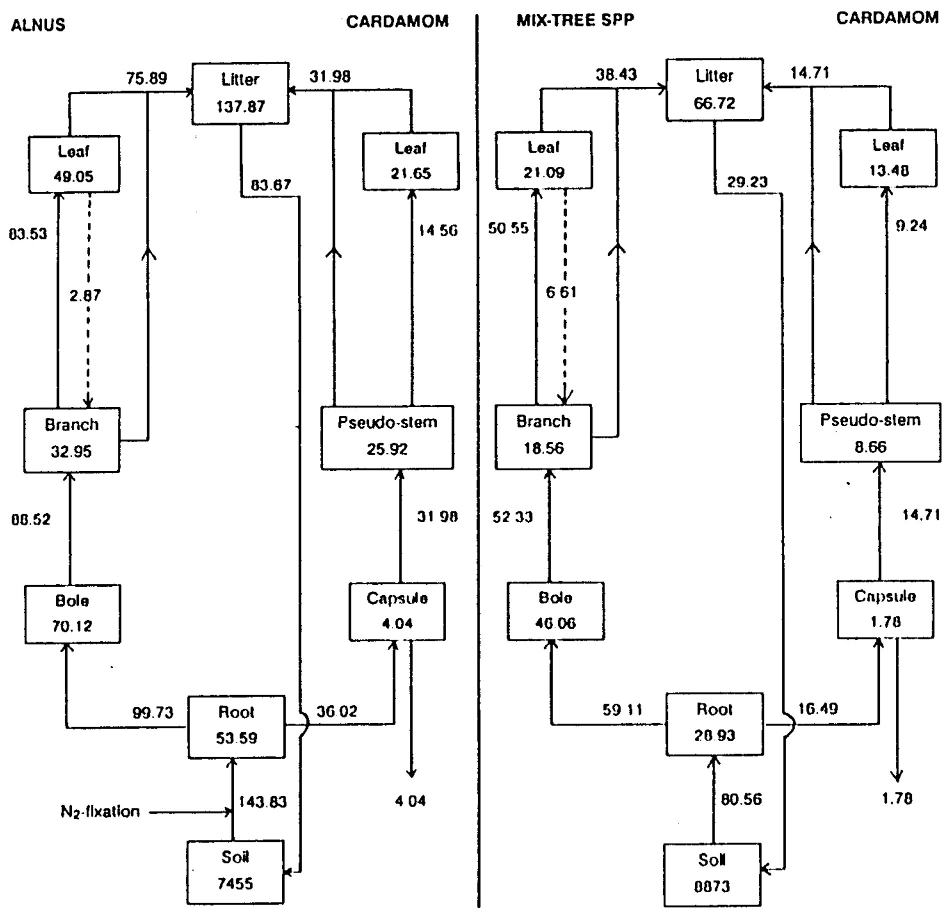

Fig. 2. Distribution of nitrogen and flow rates in the components of *Alnus*-cardamom and forest-cardamom agroforestry systems in the Mamlay watershed. Units are kg/ha for compartments and kg/ha/year for flows. Soil total nitrogen is presented for top 30 cm depth. Broken lines indicate back translocation of nitrogen from leaf to branch before abscission.

tively, 2.02, 1.80, 2.62 and 2.13 times higher in *Alnus*-cardamom than the forest-cardamom stand. The annual retention of phosphorus in plant components and litter was 6.3 kg/ha/year in the *Alnus*-cardamom stand and 3.8 kg/ha/year in the forest-cardamom stand (Fig. 3).

Nutrient use efficiency is the ratio of annual net primary productivity and nutrient uptake. The nitrogen use efficiency was 73 and 93, and phosphorus 823 and 1151 in the *Alnus*-cardamom and forest-cardamom stands, respectively.

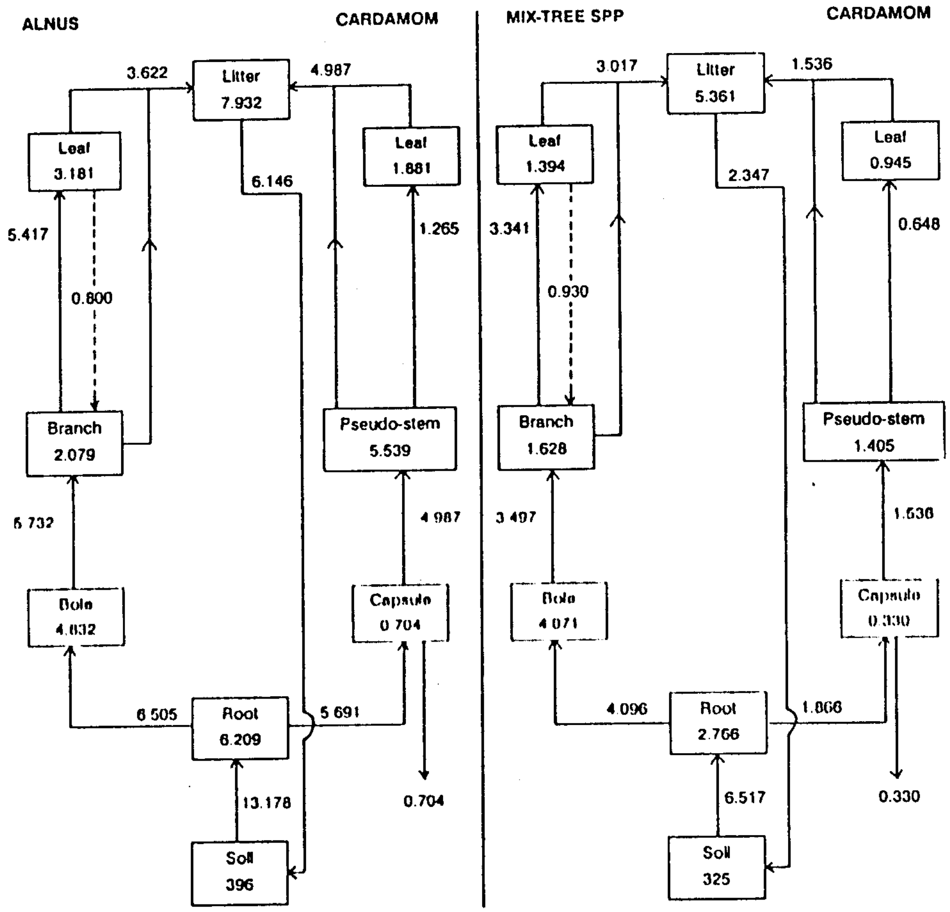

Fig. 3. Distribution of phosphorus and flow rates in the components of *Alnus*-cardamom and forest-cardamom agroforestry systems in the Mamlay watershed. Units are kg/ha/year for flows. Soil inorganic-Phosphorus is presented for top 30 cm depth. Broken lines indicate back translocation of phosphorus from leaf to branch before abscission.

Discussion and conclusions

The stand total biomass, and tiller number, basal area and biomass of cardamom crop was much higher under the influence of *Alnus*. Binkley et al. [1992] have also reported that at a low-fertility site in USA, biomass of the *Alnus*-conifer stand exceeded by 69% to that of the pure conifer stand. Annual net primary productivity of *Alnus* trees was slightly higher than mixed tree species in spite of its lower stand density, but the cardamom productivity was more than double under the influence of *Alnus*. The agronomic yield of cardamom also increased by 2.2 times under the canopy of *Alnus*. Similarly, annual net primary productivity at the age 28 in the mixed stand of Douglas-fir and *Alnus* was 2.5 times higher compared to pure Douglas-fir stand [Binkley, 1991]. The litterfall and its disappearance rate from the floor is recorded to be much greater in *Alnus*-cardamom than the forest-cardamom stand. Tarrant et al. [1969] and Binkley et al. [1992] also found much greater litterfall in mixed stands with N_2-fixing associate than in stands containing only non-N_2-fixing trees. The litter from N_2-fixing species generally decomposes faster than litter of non-N_2-fixing species as in the present study and the addition of N-fixer litter may accelerate the decomposition of other litter types. This has also been shown by Taylor et al. [1989] who found that leaf litter of *Alnus crispa* in litter bags would require about 11.5 years to reach 95% decomposition, compared with 14.5 years for leaf litter from *Populus trimuloides*. They also reported *Populus* litter mixed with *Alnus* litter in the same bag decomposed as rapidly as the *Alnus* litter.

Nitrogen and phosphorus concentrations of different tissues of *Alnus* were higher than those of mixed tree species. This is consistent with higher nutrient concentrations of N_2-fixing *Alnus* as compared to conifer in mixed condition [Binkley, 1983; Binkley et al., 1984]. Nitrogen and phosphorus back translocation from leaf before abscission was lower in *Alnus* than mixed tree species. This is because of higher availability and uptake of these elements in the *Alnus*-cardamom stand. The general concept of inverse relationship between availability and conservation stands well in this study. *Alnus* has more availability of these elements than mixed tree species and hence recorded lower back translocation indicating its poor conservation strategy.

The annual uptake and return of nitrogen to the soil in the *Alnus*-cardamom stand were higher than the forest-cardamom stand which is attributed to nitrogen fixation by *Alnus*. The rates of phosphorus uptake and return through litterfall and decomposition were also higher in *Alnus*-cardamom than the forest-cardamom stand which has probably resulted from an increase in the rate of phosphorus supply, attributable to geochemical and biological factors influenced by *Alnus*. Potential geochemical factors could be rhizosphere acidification [Gillespie and Pope, 1989] and biological factors could be rooting depth [Malcolm et al., 1985], soil enzyme activity [Ho, 1979] and organic chelates [Ae et al., 1990].

The nitrogen and phosphorus cycling in the cardamom-based agroforestry system appeared very malleable (flexible) under the influence of N_2-fixing *Alnus*. Binkley et al. [1992] have also reported generally higher uptake and return of all nutrients and greater magnitude of malleability of nutrient cycles as an influence of N_2-fixing *Alnus* consistent with the findings of this study. But there is no understanding on the mechanisms that give rise to this malleability.

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) limit production [Melillo and Gosz, 1983; Bloom et al., 1985]. The nutrient use efficiencies in the cardamom based agroforestry systems were generally consistent with this hypothesis. It decreased as an influence of N_2-fixing *Alnus*, a pattern consistent with the expectation that efficiency should decrease with increasing rates of uptake. Binkley et al. [1992] have also reported that *Alnus rubra* is much less efficient than conifers in nutrient use. Nitrogen and phosphorus use efficiencies of *Alnus nepalensis* plantations are reported to decrease with age [Sharma, 1993].

Biomass, net primary productivity and agronomic yield in cardamom based agroforestry system increased under the influence of *Alnus*. The capsules of cardamom after the harvest are cured (dried in traditional kiln) by farmers themselves and this process requires 70–80 kg of fuelwood for 100 kg of cardamom curing [Sundriyal et al., 1994b]. The higher rate of tree biomass accumulation and net primary productivity of *Alnus* can meet this fuelwood demand from the agroforestry itself. However, there is no information on the management and plantation cycle of *Alnus* as an associate species with cardamom, and this warrants immediate research attention. The agroforestry system under the influence of *Alnus* was more productive having faster rates of nutrient cycling. The poor nutrient conservation and low nutrient use efficiency of *Alnus*, and malleability of nutrient cycling under its influence make it an excellent associate promoting higher availability and faster cycling of nutrients.

Acknowledgements

G. B. Pant Institute of Himalayan Environment and Development provided necessary facilities. This work is a part of the project funded by the Department of Science and Technology, New Delhi. Dr S. C. Rai, Dr R. C. Sundriyal, Mr L. K. Rai and Ms Sabita Krishna helped in the preparation of the manuscript.

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