Agroforestry Systems **29**: 165–179, 1995.

Dry matter production and nutrient cycling in agroforestry systems of mandarin grown in association with *Albizia* and mixed tree species

R. SHARMA, E. SHARMA and A. N. PUROHIT
G.B. Pant Institute of Himalayan Environment and Development, Sikkim Unit, P.O. Tadong, Sikkim-737102, India

Key words: *Albizia stipulata* Boiv., *Citrus reticulata* Blanco, net primary productivity, nutrient back translocation, nutrient use efficiency

Abstract. A study on dry matter production and nutrient cycling in agroforestry systems of mandarin grown in association with N_2-fixing *Albizia* and mixed tree species (non-N_2-fixing) was carried out in the Sikkim Himalaya. A site with *Albizia* was referred as *Albizia*-mandarin stand and the other site with mixed tree species as mandarin stand. The stand total biomass, net primary productivity and mandarin fruit production was higher under the influence of *Albizia*. Agronomic yield of crops remained nearly the same in both the stands. Nitrogen and phosphorus concentrations of different components of *Albizia* were higher than those of mixed tree species, whereas their back translocation from leaf to branch before abscission was lower in *Albizia*. The mandarin-based agroforestry is a highly nutrient-exhaustive system evaluated in terms of nutrient exit through the removal of agronomic yield. This system, under the influence of *Albizia*, was more productive with faster rates of nutrient cycling. Nutrient use efficiency increased under the influence of *Albizia*, in contrary to the hypothesis that efficiency should decrease with increasing rate of uptake. The poor nutrient conservation of *Albizia*, and malleability of nutrient cycling under its influence make it an excellent association which promotes higher availability and faster cycling of nutrients. *Albizia* should be utilised more extensively in the management of mandarin-based agroforestry systems.

Introduction

Mandarin (*Citrus reticulata*) next to large cardamon is the second important perennial cash crop of the Sikkim Himalayan region which is cultivated in about 1772 ha areas of Sikkim [Anonymous, 1981] between elevation of 500–1500 m. Annual agronomic production of the mandarin from Sikkim amounts to about 12 million kg fetching cash equivalent of nearly 2 million US$ in 1993. It is a native citrus fruit and its cultivation requirements are more humid and subtropical summers, warmer winters and higher annual rainfall (1000 to 3000 mm) uniformly distributed from April to October. A total of 1039 holdings on mandarin cultivation has been recorded in Sikkim [Anonymous, 1981]. They are classed into different sizes of holdings: 39% of the holding are for the class below 1 ha followed by 28% for that of 1–3 ha and the remaining for higher holding sizes. The mandarin is a major source of cash income to supplement subsistence farming in subtropical conditions of the region.

Sundriyal et al. [1994a, b] have described the hill agroforestry systems of the area and their findings suggest a clear emergence of participatory development of this sector as a top priority. The agroforestry systems in the Mamlay watershed can be categorised into two major types viz (i) large cardamom-based, and (ii) multi-tier mandarin-based. Sharma et al. [1994] have described the large cardamom-based temperate agroforestry system specifically with respect to the dry matter production and biogeocycling of nitrogen and phosphorus as an effect of N_2-fixing *Alnus*. Mandarin-based agroforestry systems comprised trees, mandarin and annual crops, and are common in the subtropical belt of the Sikkim Himalaya. *Albizia* trees are grown in these agroforestry systems. Roots of *Albizia stipulata* are nodulated with *Rhizobium* as an endosymbiont and are known to fix atmospheric nitrogen [R. Sharma, E. Sharma and A. N. Purohit, unpub.]. Enhanced growth of *Eucalyptus* by planting it in a mixture with *Albizia falcataria* in Hawaii has been reported [DeBell et al., 1989]. This study was planned to (i) examine the influence of *Albizia* on stand productivity and agronomic yield of crops and mandarin with respect to mixed tree species, (ii) characterise within-system nitrogen and phosphorus fluxes and removal from the system through agronomic yield of crops and mandarin, and (iii) examine the influences of *Albizia* on the nutrient use efficiencies.

Study sites

Location and climate

The mandarin-based agroforestry systems under investigation are located within the Mamlay watershed in the south district of Sikkim in the eastern Himalaya. It is an agrarian watershed with a total area of 3009 ha [Sharma et al., 1992, 1994].

The mandarin is a perennial tree and cultivated in subtropical zone of the watershed in about 17 ha land area. The selected agroforestry site (elevation 900–1200 m) for the study is located at Koluk. The climate of the site is subtropical and the average daily temperature range between 10 to 30 °C. The annual precipitation at the site was 2030 mm in 1992. The selected stands occupy sloping topography (25–30° slope) and the aspect is south-west.

Agroforestry system

The study site was selected at Koluk in Tirikhola area of the Mamlay watershed. One plot was selected with *Albizia stipulata* and mixed tree species with mainly mandarin as tree component, and it is referred as *Albizia*-mandarin stand. The second plot was selected adjacent to the first plot with mixed tree species also having mandarin as main tree cover, and referred as the mandarin stand. None of the mixed tree species in both the plots had symbiotic association for N_2-fixation whereas *Albizia* has *Rhizobium* symbiosis and is a nitrogen fixer. In both agroforestry systems *Citrus reticulata* (mandarin) formed the main tree cover and these mandarin trees were about 14 years of age in 1993. The agriculture crops in both agroforestry systems were maize (*Zea mays*), finger millet (*Eleusine coracana*), cassava (*Manihot esculenta*) and colocasia (*Colocasia antiquorum*). Mixed tree species of both the agroforestry systems excluding *Citrus reticulata* comprised *Psidium guajava, Musa* spp., *Bombax malabaricum, Bischofia javanica, Ficus cunia and Litsaea polyantha.*

Methods

Keeping in mind the homogeneity of a stand, a sample area of 40 × 40 m was marked in each of the *Albizia*-mandarin and mandarin agroforestry systems. The homogeneity in the two selected stands was considered in terms of mandarin tree age, agriculture crop selection and cultivation, tree density, slope of the terrain and soil type. 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 stands were marked in February 1992. Trees in both stands were small with diameter at breast heights (dbh) and heights not exceeding 30 cm and 18 m, respectively. 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., 1994c]. Leaf and twig were plucked from different sizes of branches and their dry weights estimated using conversion ratio obtained from subsamples, and biomass for each tree was extrapolated by recording the size and number of branches per tree. Major roots of *A. stipulata* and mixed tree species of different sizes were excavated from current year stumps of adjoining areas and the dry weight estimated using conversion ratio. Dead uprooted mandarin trees of different sizes from nearby orchards were used for major root biomass estimation. Samples of each component were oven-dried at 80 °C to constant weight for determining fresh to dry weight ratios. The specific ratio of each component on multiplication with the estimated fresh weight yielded the dry weight for different components.

Allometric relationships of component biomass on tree dimensions for *Albizia stipulata* and mixed tree species were developed (Table 1). The dbh and heights of the same trees from both 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 in Table 1. Relative tightness of the regression was effectively expressed by estimating relative error E [Whittaker and Woodwell, 1968; Whittaker and Marks, 1975]. E reflects the error in pre-

Table 1. Regression relating component biomass with tree dimensions of *Albizia stipulata* and mixed species in sub-tropical agroforestry systems at the Mamlay watershed.

Species	Tree component	Regression equation	d.f.	*r*	*E*
Albizia stipulata	Bole	$y = \exp[5.646 + 0.653 \ln D^2H]$	7	0.992*	1.0599
	Branch	$y = \exp[4.847 + 0.572 \ln D^2H]$	7	0.997*	1.0321
	Leaf and twig	$y = \exp[5.626 + 0.233 \ln D^2H]$	7	0.871*	1.0983
	Root	$y = \exp[5.385 + 0.545 \ln D^2H]$	7	0.993*	1.0468
	Total	$y = \exp[6.654 + 0.586 \ln D^2H]$	7	0.996*	1.0361
Mixed tree species	Bole	$y = \exp[5.653 + 0.595 \ln D^2H]$	21	0.964*	1.0545
	Branch	$y = \exp[5.484 + 0.443 \ln D^2H]$	21	0.938*	1.0545
	Leaf and twig	$y = \exp[5.737 + 0.281 \ln D^2H]$	21	0.911*	1.0421
	Root	$y = \exp[5.503 + 0.485 \ln D^2H]$	21	0.939*	1.0593
	Total	$y = \exp[6.831 + 0.513 \ln D^2H]$	21	0.959*	1.0505

y = tree component biomass (g); D = diameter at breast height (cm); H = height (m); d.f. = degree of freedom; *r* = coefficient of correlation; and *E* = relative error calculated as antilog of the standard error of natural logarithm of the y-value.
* Significant at $p < 0.01$.

dicting natural logs of value and is a more useful predictor than the least square standard error of estimate [Sprugel, 1984]. The relationships between the actual estimated and predicted component biomass for *A. stipulata* 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 litter-fall 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. Accumulated litter on the floor 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 total numbers of mandarin fruits for all the trees were counted and extrapolated to stand values. A large number of mandarin fruits of different sizes were weighed and average fresh weight per fruit was estimated for converting mandarin fruit production on fresh weight basis. Subsamples were dried in an oven to a constant weight at 65 °C for dry weight conversion. Maize, finger millet, cassava and colocasia were the four crops cultivated in these agroforestry systems. Area cropped (per ha) and number of plants (per ha) of each crop in the *Albizia*-mandarin and mandarin agroforestry systems were recorded. Agronomic yield, above-ground and below-ground crop residues of each crop on unit area or plant or bush basis were estimated at the time of crop maturation in each stand in 1993. Below-ground residues were estimated after excavation of up to 30 cm depth of soil. These estimations were made by harvesting the crops at maturation in 1 m^2 area or plant/bush basis in replicates.

Decomposition studies were carried out by enclosing litter fraction (*Albizia* leaf, *Albizia* twig, mixed species leaf, mixed species twig and mixed crop residue) separately in nylon bags measuring 10 × 10 cm with 1-mm mesh size [Bocock et al., 1960; Sharma and Ambasht, 1987]. Air-dried samples were enclosed in bags and placed on the floor in the stands in a randomised block design. The bags were randomly sampled in replicates of five from each stand at each collection time and annual mass loss and nutrient (N and P) release from each fraction estimated. The values of all the fractions of litter was pooled and annual mass loss and nutrient release on unit area basis was calculated for both agroforestry systems.

Soil samples of 0–15 and 15–30 cm depths from 0.5, 1.0 and 1.5 m from the base of three trees in each stand were collected in replicates (n = 3) in autumn, winter, spring and rainy seasons. Starting with the tree distance of about 7 m, the sampling was done up to 3 m from the base of a tree but no significant difference was observed in the nutrient values of 1.5 and 3 m distances, hence data of up to 1.5 m was presented. The soil samples were air dried, ground and passed through a 2-mm sieve and used for nutrient analysis. Soil total nitrogen was estimated using a 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 was estimated from bulk density, soil volume and nutrient concentration values. The amounts of nutrients estimated in both horizons were summed to obtain total content down to 30 cm depth.

Mandarin fruits were oven dried and fresh weight to dry weight ratios were calculated. Oven-dried samples of all tree and crop components were ground to pass a 2-mm sieve. Plant samples (0.5 g) were combusted in a porcelain crucible at 550 °C for 1 hour after adding 2 ml saturated solution of magnesium nitrate to prevent phosphorus volatilisation [Horwitz, 1980]. Ash was dissolved in 1 M HCl and phosphorus analysed by sulphomolybdophosphoric blue colour method [Jackson, 1973]. Plant total nitrogen was estimated using a modified Kjeldahl method [Anderson and Ingram, 1989]. Nitrogen and phosphorus concentrations of intact and freshly fallen leaves were estimated, and back translocation in *Albizia* and mixed tree species at leaf abscission calculated. The nutrient contents of tree and crop components were computed by multiplying component biomass with respective nutrient concentration. Nutrient flow from leaf and twig and crop residues to floor was estimated through litterfall, crop residues and their nutrient concentration estimations. The mean nutrient content of floor litter/crop residues was estimated by analysing samples at three random (1 m^2) areas in each stand. The sum of nutrient contents of trees, crop and floor litter/crop residues 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 the return through decomposition of the floor litter/crop residues.

Results

Densities of trees per ha were 56, 106 and 38 for *Albizia stipulata, Citrus reticulata* and mixed species, respectively, with a total tree basal area of 2.89 m^2/ha in the *Albizia*-mandarin agroforestry system. In the mandarin agroforestry system tree basal area was 2.62 m^2/ha with 113 trees/ha of *Citrus reticulata* and 69 trees/ha of mixed species.

Total biomass was 20% higher in the *Albizia*-mandarin stand than in the mandarin stand. Tree biomass was also higher by 29% (Table 2) with the total number of trees slightly more (18 trees/ha) in the *Albizia*-mandarin stand.

Table 2. Biomass and productivity (1992–3) of components in sub-tropical agroforestry systems of the Mamlay watershed.

Agroforestry systems	Components	Biomass (kg/ha)	Productivity (kg/ha/year)
Albizia-mandarin	Tree (*Albizia*)		
	Bole	3581	591
	Branch	800	152
	Leaf and twig	100	218[a]
	Root	1086	157
	Tree (mixed spp.)		
	Bole	1696	299
	Branch	494	74
	Leaf and twig	225	1293[a]
	Root	670	108
	Orange fruits	771	771
	Trees total	9423	3663
	Crops		
	Above-ground residue	2238	2238
	Below-ground residue	633	633
	Agronomic yield	1585	1585
	Crop total	4456	4456
	Stand total	13879	8119
Mandarin	Tree (mixed spp.)		
	Bole	3505	364
	Branch	892	82
	Leaf and twig	348	1657[a]
	Root	1258	121
	Orange fruit	641	641
	Trees total	6644	2865
	Crops		
	Above-ground residue	2172	2172
	Below-ground residue	768	768
	Agronomic yield	1553	1553
	Crop total	4493	4493
	Stand total	11137	7358

[a] Tree leaf and twig production estimated on standing trees was corrected using litterfall data and estimated fodder removal from undisturbed sub-plot.

The contribution of crop biomass was almost the same in both stands. Contributions of trees and crops were, respectively, 45% and 55% to the annual net primary productivity in the *Albizia*-mandarin stand, whereas it was 39% for trees and 61% for crops in the mandarin stand. The stand net primary productivity was higher by 761 kg/ha/year in the *Albizia*-mandarin than in the mandarin stand (Table 2). Annual contribution of major root production was almost equal in both stands (Fig. 1). Agronomic yield on a unit area basis was higher for maize, cassava and colocasia in the mandarin stand whereas finger millet was higher in the *Albizia*-mandarin stand. Crop residues both above- and below-ground for all crops were higher in the mandarin stand (Table 3). But on the basis of total cropped area by each crop in a hectare area of agroforestry, the agronomic yield and above-ground crop residue production were slightly more in the *Albizia*-mandarin stand (Table 4). All these crops (maize, finger millet, cassava and colocasia) are cultivated by farmers

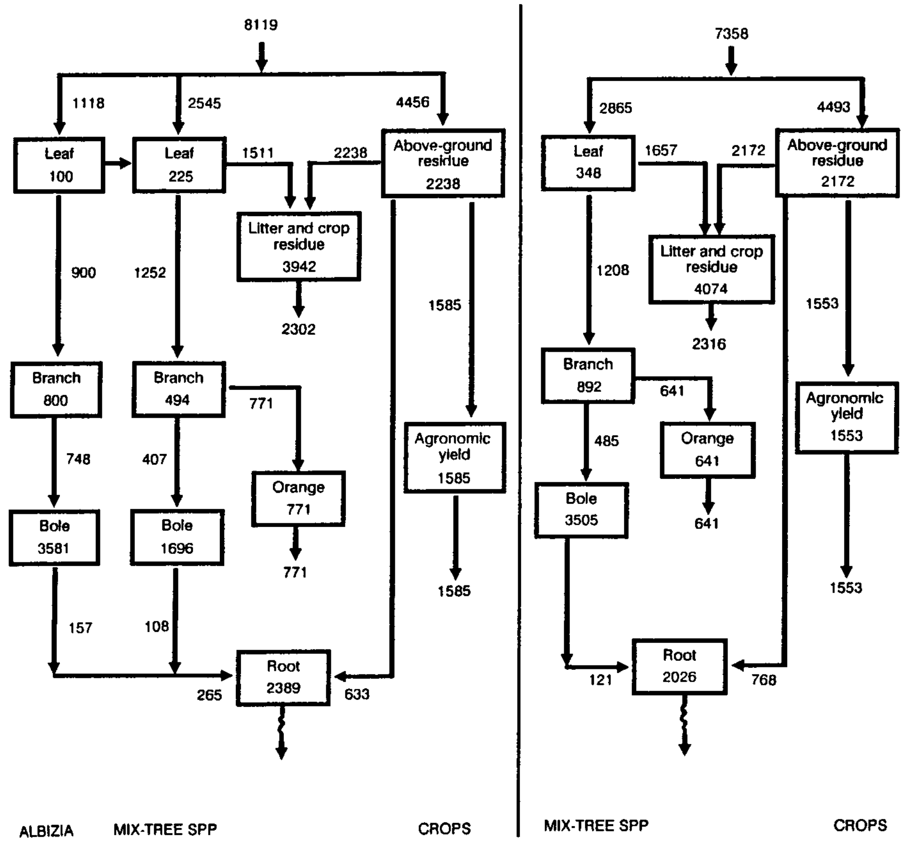

Fig. 1. Compartment model showing distribution of dry matter biomass, net primary production, litter disappearance rate and orange fruit harvest in *Albizia*-mandarin and mandarin agroforestry systems in Mamlay watershed. Units are kg/ha for compartments and kg/ha/year for flows.

Table 3. Agronomic yield and crop residue production on unit area or per plant basis in sub-tropical agroforestry systems of the Mamlay watershed.

Agroforestry systems	Crop[a]	Agronomic yield	Above-ground crop residue	Below-ground crop residue
Albizia-mandarin	Maize (g/m^2)	218 ± 05	326 ± 15	78 ± 04
	Fingermillet (g/m^2)	78 ± 03	114 ± 07	45 ± 01
	Cassava (kg/plant)	1.48 ± 0.14	1.13 ± 0.24	0.62 ± 0.11
	Colocasia (kg/bush)	1.69 ± 0.23	2.41 ± 0.38	1.13 ± 0.23
Mandarin	Maize (g/m^2)	240 ± 07	348 ± 28	108 ± 04
	Fingermillet (g/m^2)	72 ± 03	128 ± 08	53 ± 06
	Cassava (kg/plant)	1.74 ± 0.34	1.27 ± 0.18	0.74 ± 0.14
	Colocasia (kg/bush)	1.82 ± 0.26	2.71 ± 0.22	1.32 ± 0.16

[a] Maize = *Zea mays*; fingermillet = *Eleusine coracana*; cassava = *Manihot esculenta*; and colocasia = *Colocasia antiquorum*.

Table 4. Area cropped (per ha) and annual agronomic yield and crop residue production (kg/ha) in sub-tropical agroforestry systems of the Mamlay watershed.

Agroforestry system	Crop	Area cropped (ha) or number of plants/ha	Agronomic yield	Above-ground crop residue	Below-ground crop residue
Albizia-mandarin	Maize	0.56	1221	1826	437
	Fingermillet	0.09	70	103	41
	Cassava	113*	167	128	70
	Colocasia	75*	127	181	85
	Total	1.00	1585	2238	633
Mandarin	Maize	0.47	1128	1636	508
	Fingermillet	0.14	101	179	74
	Cassava	94*	164	119	70
	Colocasia	88*	160	238	116
	Total	1.00	1553	2172	768

* Number of plants/ha.

for their family consumption, except for mandarin fruit which fetches cash income. The mandarin fruit production (on fresh weight basis) was 1.2 times greater in spite of lower number (7 trees/ha less) of *Citrus* trees in the *Albizia*-mandarin stand than in the mandarin stand. Actual annual cash income from mandarin fruit in the *Albizia*-mandarin system with the current year prices (40 paise per fruit in the nearest market) was equivalent to 680 US$ per ha against 560 US$ with the mandarin stand.

Contribution of tree litter was 40% and crop residue 60% to the stand total annual litter/crop residue flow to floor in the *Albizia*-mandarin agroforestry system. The 61% of annual litter/crop residue production are decomposed while 39% accumulated on the floor. Similarly, tree litter contributed 43% and crop residue 57% to the stand total annual litter/crop residue production in the mandarin stand, and the rate of accumulation on the floor was 40% of the annual production (Fig. 1). The litter/crop residue production was slightly lower in the *Albizia*-mandarin than in the mandarin stand. There were not much variations on litter production and disappearance rates between the *Albizia*-mandarin and mandarin stands.

Nitrogen and phosphorus concentrations of different plant components of *Albizia* tree were higher than those in the mixed tree species: nitrogen in bole by 1.26 times, branch 1.05, leaf and twig 1.97 and root 1.86; phosphorus in bole by 1.47 times, branch 2.30, leaf and twig 1.39 and root 1.96 (Table 5). Nitrogen and phosphorus concentrations of intact and freshly fallen leaves of *Albizia* and mixed tree species were estimated and given in Table 6. Back translocation of nitrogen from leaf to branch before abscission was only 1.43% and phosphorus 9.42% in *Albizia* while it was 19.77% nitrogen and 29.67%

Table 5. Nitrogen and phosphorus concentrations in different plant components of sub-tropical agroforestry systems in the Mamlay watershed. Values are mean ± 1SE ($n = 10$).

Component	Nitrogen (%)	Phosphorus (%)
Albizia stipulata		
Bole	0.68 ± 0.05	0.066 ± 0.008
Branch	0.82 ± 0.02	0.175 ± 0.019
Leaf and twig	3.21 ± 0.14	0.192 ± 0.036
Root	1.21 ± 0.03	0.212 ± 0.014
Mixed tree spp.		
Bole	0.54 ± 0.03	0.045 ± 0.004
Branch	0.78 ± 0.05	0.076 ± 0.009
Leaf and twig	1.63 ± 0.11	0.138 ± 0.013
Root	0.65 ± 0.06	0.108 ± 0.008
Orange fruit	0.74 ± 0.01	0.109 ± 0.006
Crops		
Above-ground residue	1.81 ± 0.16	0.232 ± 0.020
Below-ground residue	0.93 ± 0.07	0.184 ± 0.031
Agronomic yield	2.43 ± 0.19	0.314 ± 0.036

Table 6. Nitrogen and phosphorus concentration (mg/g) of intact and freshly-fallen leaves, and back translocation (%) of tree species from sub-tropical agroforestry systems in the Mamlay watershed. Concentration values are mean ($n = 10$) ± 1SE.

Agroforestry system	Species	Leaf type/translocation	Nitrogen	Phosphorus
Albizia-mandarin	*Albizia*	Intact leaf	34.9 ± 0.48	2.23 ± 0.08
		Freshly fallen leaf	34.4 ± 0.59	2.02 ± 0.11
		Back translocation	1.43	9.42
Mandarin	Mixed spp.	Intact leaf	17.2 ± 0.52	1.82 ± 0.14
		Freshly fallen leaf	13.8 ± 0.37	1.28 ± 0.12
		Back translocation	19.77	29.67

phosphorus in the mixed tree species (Table 6). Absolute amounts of nitrogen and phosphorus back translocation were respectively, 1.25 and 1.20 times higher in trees of the mandarin stand than in trees of the *Albizia*-mandarin stand (Figs 2 and 3).

Soil total nitrogen level of up to the 30 cm depth in the *Albizia*-mandarin stand was 1.08 times higher than that in the mandarin stand (Fig. 2). The annual retention of nitrogen in plant components and litter/crop residue was slightly higher in the *Albizia*-mandarin stand (46.80 kg/ha/year) than in the mandarin stand (40.87 kg/ha/year). Annual uptake, standing state, return to soil and exit of nitrogen from the systems were, respectively, 1.08, 1.23, 1.08 and 1.04 times higher in the *Albizia*-mandarin stand than in the mandarin stand.

Soil inorganic phosphorus of up to the 30 cm depth was higher in the mandarin stand than in the *Albizia*-mandarin stand (Fig. 3). Total annual phosphorus uptake, standing state, return to soil and exit from the systems were, respectively, 1.06, 1.19, 1.03 and 1.04 times higher in the *Albizia*-mandarin stand than in the mandarin stand. The annual retention of phosphorus in plant

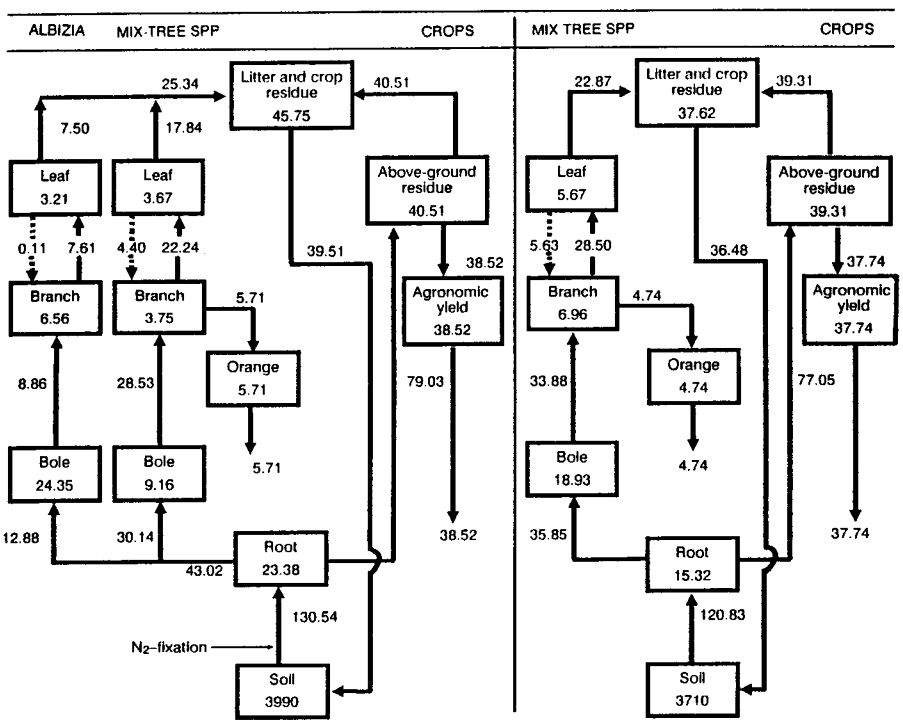

Fig. 2. Distribution of nitrogen and flow rates in the components of *Albizia*-mandarin and mandarin agroforestry systems in the Mamlay watershed. Units are kg/ha for compartments and kg/ha/year for flows. Soil total nitrogen is presented for top 30 cm depth. Broken lines indicate back translocation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

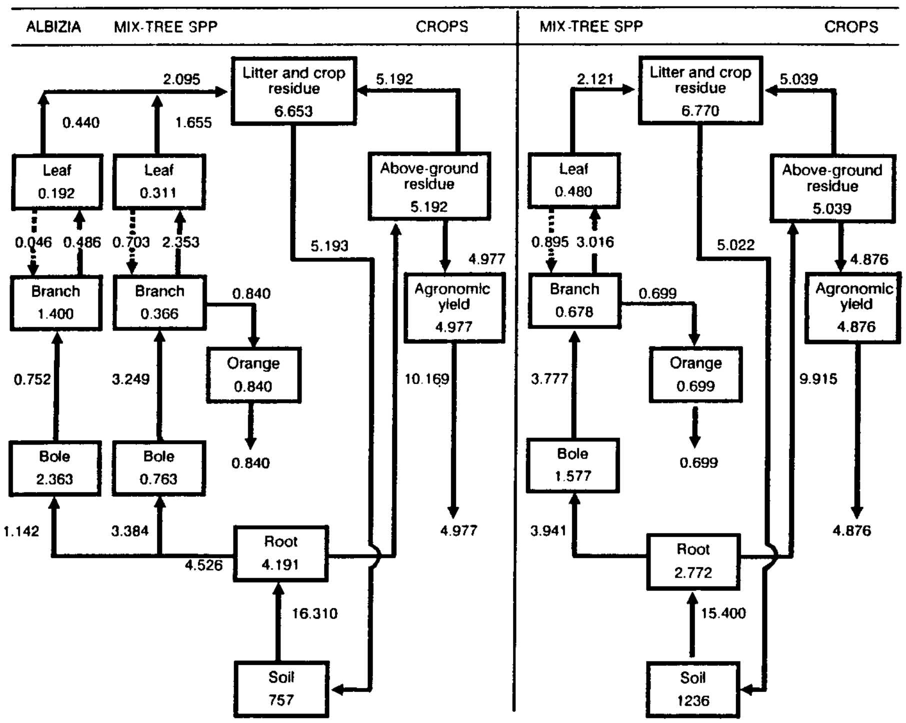

Fig. 3. Distribution of phosphorus and flow rates in the components of *Albizia*-mandarin and mandarin agroforestry systems in the Mamlay watershed. Units are kg/ha for compartments and kg/ha/year for flows. Soil inorganic-P is presented for top 30 cm depth. Broken lines indicate back translocation of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

components and litter/crop residue was 5.3 kg/ha/year in the *Albizia*-mandarin stand and 4.8 kg/ha/year in the mandarin stand (Fig. 3).

Nutrient use efficiency is the ratio of annual net primary productivity and nutrient uptake. The nitrogen use efficiency was 87 and 83, and phosphorus 695 and 651 in the *Albizia*-mandarin and mandarin stands, respectively.

Discussion and conclusions

The stand total biomass, tree biomass and basal area were higher under the influence of *Albizia*. Similarly, DeBell et al. [1989] reported that in Hawaii the growth of *Eucalyptus saligna* has been enhanced by planting the species in a mixture with *Albizia falcataria*. The contribution of crop biomass was almost the same in both the *Albizia*-mandarin and mandarin stands. However mandarin fruit production was higher (by 1.2 times) in the *Albizia*-mandarin stand. In contrast, in the case of cardamom-based temperate agroforestry systems in the same watershed, 2.5 times higher cardamom biomass was estimated in stand having N_2-fixing *Alnus* as shade trees [Sharma et al., 1994]. The more pronounced effect of N_2-fixing trees on large cardamom biomass in the *Alnus*-cardamom system could be due to a much higher density of N_2-fixing *Alnus* (517 trees/ha) than *Albizia* (56 trees/ha) in the selected subtropical agroforestry system. Annual net primary productivity of the mandarin stand was about 90% of that of *Albizia*-mandarin stand. Similarly, in cardamom-based temperate agroforestry system mixed tree species contribution to the net annual productivity was lower (69%) than that of N_2-fixing *Alnus* associate [Sharma et al., 1994]. Production and disappearance rates of litter/crop residue were slightly lower in the *Albizia*-mandarin stand than in the mandarin stand. Binkley [1992] also reported that in Hawaii, *Eucalyptus* in a mixture of up to 50% with *Albizia* produced less litter biomass as compared to pure *Eucalyptus*. This could be due to the fact that *Albizia* leaves are fine, thin and light as compared to those of associates. However, Tarrant et al. [1969], Binkley et al. [1992] and Sharma et al. [1994] have reported much greater litterfall in mixed stands with N_2-fixing associate than in stands containing only non-N_2-fixing trees.

Nitrogen and phosphorus concentrations of different tissues of *Albizia* were higher than those of mixed tree species. This is consistent with higher nitrogen and phosphorus concentrations of N_2-fixing species as compared to associates in a mixed condition [Binkley, 1983; Binkley et al., 1984]. Sharma et al. [1994] have also reported higher concentration of nitrogen and phosphorus in N_2-fixing *Alnus* as compared to non-N_2-fixing mixed tree species of an adjacent stand in large cardamom-based agroforestry systems in the same watershed. Nitrogen and phosphorus back translocation from leaf to branch before abscission was lower in *Albizia* than in mixed tree species. This is because of higher availability and uptake of these elements in the *Albizia*-mandarin stand. Similar results were reported for *Alnus* and mixed tree species in cardamom-based agroforestry systems [Sharma et al., 1994]. The general concept of inverse relationship between availability and conservation stands well in this study. *Albizia* has greater availability of these elements than the mixed tree species. *Albizia* had lower back translocation indicating its poor conservation strategy.

The annual uptake and return of nitrogen to the soil in the *Albizia*-mandarin stand were higher than in the mandarin stand which is attributed to nitrogen fixation by *Albizia*. The rates of phosphorus uptake and return through litterfall and decomposition were also higher in the *Albizia*-mandarin stand than in the mandarin stand which has probably resulted from an increase in the rate of phosphorus supply, attributable to geochemical and biological factors influenced by *Albizia*. Similar results were reported in *Alnus*-cardamom agroforestry systems of the same watershed [Sharma et al., 1994]. 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 mandarin-based agroforestry is a highly nutrient exhaustive system as compared to large cardamom-based agroforestry of the same watershed [Sharma et al., 1994] evaluated on annual nutrient exit from the system through removal of agronomic yield. Pooled data for both agroforestry systems show that mandarin-based agroforestry is 15 times more exhaustive for nitrogen and 11 times for phosphorus than the large cardamom-based agroforestry.

The nitrogen and phosphorus cycling in mandarin-based agroforestry system appeared to be malleable (flexible) under the influence of N_2-fixing *Albizia*. The magnitude of malleability of nutrient cycling was much greater for large cardamom-based agroforesty of the same watershed under the influence of N_2-fixing *Alnus* [Sharma et al., 1994] than the present stand under *Albizia* influence. This could be because of the much higher density of *Alnus* than *Albizia*, which subsequently influencing with greater magnitude. 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 species. The mechanisms that give rise to the malleability is not yet understood.

Nutrient use efficiency may be expected to drop since on the one hand utilisation of that nutrient increases but on the other hand the availability of some other resource (such as water, energy or light) limits the production [Melillo and Gosz, 1983; Bloom et al., 1985]. The nutrient use efficiency is consistent with this hypothesis in the large cardamom-based agroforestry systems of the Mamlay watershed under the influence of N_2-fixing *Alnus* [Sharma et al., 1994]. Binkley et al. [1992] have also reported that N_2-fixing *Alnus rubra* is much less efficient than conifers in nutrient use, while Sharma [1993] reported a decrease in nutrient use efficiencies with plantation age in *Alnus nepalensis*. The hypothesis is true in stabilized and temperate conditions. Nutrient use efficiency increased due to the influence of N_2-fixing associate *Albizia* as shown in the present study, in contrary to the expectation and hypothesis that efficiency should decrease with increasing rate of uptake. The reasons could be (a) a lower density of N_2-fixing *Albizia* in the stand, (b) the site being located in subtropical climate thus other factors such as temperature and light were not limiting, and (c) threshold level of production and nutrient uptake did not match due to the fragility of agroforestry soil disturbed during the raising of annual crops.

Biomass and net primary productivity of the stand, and mandarin fruit production in mandarin-based agroforestry system increased under the influence of *Albizia*. Agronomic yield of crops remained nearly the same in both the *Albizia*-mandarin and mandarin stands. The agroforestry system under the influence of *Albizia* was more productive with faster rates of nutrient cycling. The poor nutrient conservation of *Albizia* and malleability of nutrient cycling under its influence make it an excellent associate which promotes higher availability and faster cycling of nutrients. The mandarin-based agroforestry is a highly nutrient-exhaustive system. Therefore, the role of N_2-fixing species such as *Albizia* could be indispensable in efficiently managing the mandarin-based agroforestry systems. However, there is no information on the management, planting density and plantation cycling of *Albizia* as an associate species with mandarin, and this warrants an immediate research attention. Understanding of mechanisms for malleability of nutrient cycling under the influence of *Albizia* needs further experimentation.

Acknowledgements

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

References

Ae N, Arihara J, Okada K, Yoshihara T and Johansen C (1990) Phosphorus uptake by pigeon pea and its role in cropping systems of the Indian subcontinent. Science 248: 477–480

Anderson JM and Ingram JSI (1989) Tropical Soil Biology and Fertility: A Handbook of Methods. CAB International, UK

Anonymous (1981) Agriculture Census of Sikkim, Government of Sikkim, India

Binkley D (1983) Interaction of site fertility and red alder on ecosystem production in douglas-fir plantations. Forest Ecology and Management 5: 215–227

Binkley D (1992) Ecology of mixtures of nitrogen-fixing and non-nitrogen-fixing tree species. In: Canell MGR, Malcolm DC and Robertson PA (eds) The Ecology of Mixed Species Stands of Trees, pp 99–123. Blackwell Scientific Publications, Oxford, UK

Binkley D, Lousier JD and Cromack Jr K (1984) Ecosystem effects of Sitka alder in a Douglas-fir plantation. Forest Science 30: 26–35

Binkley D, Sollins P, Bell R, Sachs D and Myrold D (1992) Biogeochemistry of adjacent conifer and alder/conifer stands. Ecology 73: 2022–2033

Bloom A, Chapin III FS and Mooney H (1985) Resource limitation in plants – an economic analogy. Annual Review of Ecology and Systematics 16: 363–392

Bocock KL, Gilbert OJ, Capstick CK, Turner DC, Ward JS and Woodman MJ (1960) Changes in leaf litter when placed on the surface of soil with constrasting humus types. Journal of Soil Science 11: 1–9

DeBell DS, Whitesell CD and Schubert TH (1989) Using N_2-fixing *Albizia* to increase growth of *Eucalyptus* plantations in Hawaii. Forest Science 35: 64–75

Gillespie AR and Pope PE (1989) Alfalfa N_2-fixation enhances the phosphorus uptake of walnut in interplantings. Plant and Soil 113: 291–293

Ho I (1979) Acid phosphatase activity in forest soil. Forest Science 25: 567–568

Horwitz W, ed (1980) Methods of Analysis. Association of Official Analytical Chemists, Benjamin Franklin Station, Washington, DC, USA

Jackson ML (1973) Soil Chemical Analysis. Prentice-Hall of India Pvt Ltd, New Delhi, India

Malcolm DC, Hooker J and Wheeler CT (1985) *Frankia* symbioses as a source of nitrogen in forestry: a case study of symbiotic nitrogen-fixation in a mixed *Alnus-Picea* plantation in Scotland. Proceedings of the Royal Society of Edinburgh 85B: 263–282

Melillo JM and Gosz J (1983) Interactions of biogeochemical cycles in forest ecosystems. In: Bolin B and Cook R (eds) The Major Biogeochemical Cycles and Their Interactions, pp 177–221. Wiley, New York

Ruark GA, Martin GL and Bockheim JG (1987) Composition of constant and varibale allometric ratios for estimating *Populus tremuloides* biomass. Forest Science 33: 294–300

Sharma E (1993) Nutrient dynamics in Himalayan alder plantations. Annals of Botany 72: 329–336

Sharma E and Ambasht RS (1987) Litterfall, decomposition and nutrient release in an age sequence of *Alnus nepalensis* plantation stands in the eastern Himalayas. Journal of Ecology 75: 997–1010

Sharma E, Sundriyal RC, Rai SC, Bhatt YK, Rai LK, Sharma R and Rai YK (1992) Integrated Watershed Management: A Case Study in Sikkim Himalaya. Gyanodaya Prakashan, Nainital, India

Sharma R, Sharma E and Purohit AN (1994) Dry matter production and nutrient cycling in agroforestry systems of cardamom grown under *Alnus* and natural forest. Agroforestry Systems 27: 293–306

Sprugel DG (1984) Density, biomass, productivity and nutrient cycling changes during stand development in wave-regenerated balsam fir forests. Ecological Monographs 54: 165–186

Sundriyal RC, Rai SC, Sharma E and Rai YK (1994a) Hill agroforestry system in south Sikkim, India. Agroforestry Systems 26: 215–235

Sundriyal RC, Rai SC and Sharma E (1994b) Watershed-based participatory development strategy in Sikkim. In: Lama MP (ed) Sikkim: Society, Polity, Economy and Environment, pp 178–194. Indus Publication House, Delhi

Sundriyal RC, Sharma E, Rai LK and Rai SC (1994c) Tree structure, regeneration and woody biomass removal in a subtropical forest of Mamlay watershed in the Sikkim Himalaya. Vegetatio 113: 53–63

Tarrant RF, Lu KC, Bollen W and Franklin JF (1969) Nitrogen enrichment of two forest ecosystems by red alder. United States Forest Service Research Paper PNW-76

Whittaker RH and Marks PL (1975) Methods of assessing terrestrial productivity. In: Lieth H and Whittaker RH (eds) Primary Productivity of the Biosphere, pp 55–118. Springer-Verlag, New York

Whittaker RH and Woodwell GM (1968) Dimension and production relations of trees and shrubs in the Brookhaven forest, New York. Journal of Ecology 56: 1–25