PRODUCTION, NUTRIENT DYNAMICS AND BREAKDOWN OF LEAF LITTER IN SIX FOREST PLANTATIONS RAISED ON GRAVELLY FLOOD PLAINS IN THE LOWER WESTERN HIMALAYAS

A. Raizada, C. Singh & G. Singh

Central Soil and Water Conservation Research and Training Institute, Dehra Dun - 248 195 (Uttaranchal), India

Received July 2000

RAIZADA, A., SINGH, C. & SINGH, G. 2002. Production, nutrient dynamics and breakdown of leaf litter in six forest plantations raised on gravelly flood plains in the lower Western Himalayas. Leaf litter production, nutrient returns, retranslocation patterns and breakdown of confined litter were determined in plantations of six tree species that have been raised on gravelly flood plains in the Doon Valley (Uttaranchal, India). Leaf litter production values (t ha^{-1}) followed the order of bamboo (*Dendrocalamus* and *Bambusa* sp.) (4.25) > *Eucalyptus* (2.97) > *Bauhinia purpurea* (2.86) > *Grewia optiva* (2.63) > *Melia azedarach* (2.61) > *Morus alba* (2.35). Retranslocation of nutrients varied between evergreens and deciduous species. Maximum N was retranslocated in *M. alba* (84%) and least in bamboo (16%). The half-life of confined leaf litter ranged between 0.561 and 1.128, with breakdown being fairly rapid in deciduous species. Fractional annual turnover rate varied between elements and species, with N having the highest values (68–92%) and Mg the least (13–62%). The impact of these plantations on soil physico-chemical properties were not significant in the top surface layers (0–7.5 cm).

Key words: Poor site - nutrients - retranslocation - turnover - half-life

RAIZADA, A., SINGH, C. & SINGH, G. 2002. Pengeluaran, dinamik nutrien dan penguraian sarap daun di enam ladang hutan yang ditanam di dataran banjir berkerikil di bahagian bawah Himalaya Barat. Pengeluaran sarap daun, pengembalian nutrien, pola translokasi semula dan penguraian atas sarap yang terbatas ditentukan di ladang enam spesies pokok yang ditanam di dataran banjir berkerikil di Doon Valley (Uttaranchal, India). Nilai pengeluaran sarap daun (t ha^{-1}) mengikut susunan berikut iaitu buluh (*Dendrocalamus* dan *Bambusa* sp.) (4.25) > *Eucalyptus* (2.97) > *Bauhinia purpurea* (2.86) > *Grewia optiva* (2.63) > *Melia azedarach* (2.61) > *Morus alba* (2.35). Translokasi semula nutrien berbeza antara spesies malar hijau dan spesies daun luruh. Nilai maksimum bagi translokasi semula N ialah dalam *M. alba* (84%) dan paling sedikit dalam buluh (16%). Separuh hayat sarap daun yang terbatas berjulat antara 0.561 hingga 1.128, dengan penguraian agak pantas dalam spesies daun luruh. Kadar perolehan tahunan berperingkat berbeza antara unsur dan spesies, dengan nitrogen mempunyai nilai tertinggi (68–92%) dan magnesium paling sedikit (13–62%). Kesan ladang ini terhadap ciri-ciri fiziko-kimia tanih tidak bererti dalam lapisan permukaan atas (0–7.5 cm).

Introduction

Reclamation forestry on degraded sites using native and exotic species is now advocated for soil conservation and amelioration and also to meet the demands of fuelwood and fodder. Organic matter returned to the soil surface layer by way of litter production and its subsequent breakdown and mineralisation are important pathways in sustaining a dynamic forest ecosystem. Litter production is influenced by several factors (Meentemeyer *et al.* 1982) while the nature of plant and nutrient availability influence biochemical mineral flow pathways in standing trees. Metabolically active leaves continue to draw nutrients from the soil until they attain maturity. Subsequently, nutrient content often declines as a result of retranslocation prior to senescence (Charley & Richards 1983). Resorption of nutrients from senescing leaves enables plants to reuse these nutrients and it is, therefore, a nutrient-conservation mechanism (Aerts 1990). This mechanism of low nutrient loss can increase the fitness of plants in nutrient poor sites (Grime 1979, Chapin 1980) and also lead to higher equilibrium biomass (Aerts & van der Peijl 1993). Nutrients that are left behind in senescent leaves eventually reach the soil where the litter are decomposed and eventually mineralised for nutrients to become once again available for plant uptake.

A number of studies on litter production and nutrient cycling in India have been carried out covering several species in natural high forests and in plantations. Nutrient estimation in litter fall has been reported in *Pinus kesiya* (Das & Ramakrishnan 1985), *P. roxburghii* (Seth *et al.* 1963, Srivastava *et al.* 1972, Sharma & Pande 1989), *Tectona grandis* (Seth *et al.* 1963, Sharma & Pande 1989), *Shorea robusta* (Srivastava *et al.* 1972, Sharma & Pande 1989), *Populus deltoides* (Raizada & Srivastava 1991), *Eucalyptus* (Sharma & Pande 1989) and in *Dendrocalamus strictus* (Tripathi & Singh 1994).

In this paper we report on the seasonality of litter production, nutrients retranslocated and returned from the standing crop, and rates of leaf litter breakdown in six tree species that have been raised on gravelly flood plains in the lower western Himalayan region.

Materials and methods

Location of the study area

Plantations of six tree species have been raised on an old flood plain at Dehra Dun situated at 70° 52' 12" E longitude and 30° 2' 4" N latitude at an elevation of 517 m. Annual rainfall (averaged from 1956–1998) is 1646 mm received in 82 rainy days. The site contains a veneer of soil, varying in depth from 10–40 cm, that has been deposited over layers of older deposited materials which consist of stones, gravels, small and large boulders, that have been carried across sloping areas by water and deposited over these flood plains over many years. These soils have been classified as sandy, skeletal typic ustifluent soils (Bhardwaj & Singh 1981). Infiltration rates at these sites are high (2.13 to 3.00 mm $hour^{-1}$)

and may be attributed to the texture of the soil and a highly permeable stony layer at lower depths. Soils are poor in available P_2O_5 and moderate in total nitrogen (N). A typical soil profile excavated at this site by earlier workers is given in Table 1.

Table 1 Typical physico-chemical properties of soils in the flood plain area

Characteristics	Depth (cm) 0–10	10–60	60–75	75–90	90–100
Soil: stone ratio (volume basis)	70:30	20:80	45:55	30:70	15:85
Mechanical analysis of fine fraction (< 2 mm)					
Coarse sand (%)	3	35	77	51	74
Fine sand (%)	60	50	7	13	15
Silt (%)	24	6	6	18	8
Clay (%)	13	9	10	18	3
pH	6.0	6.5	6.5	6.5	6.6
Total N (%)	0.07	0.04	0.08	0.07	0.02
Available P_2O_5 (kg ha^{-1})	18.7	18.8	20.0	18.1	19.2
Available K_2O (kg ha^{-1})	176.4	172.8	144.0	130.4	120.7

Plantations of six species, which include a plantation of mixed species of bamboos (*D. strictus* and *Bambusa giganteus*, planted at irregular spacing) were raised on these flood plains with a view to evaluate their growth rates and the impact of these plantations on soil properties. The other species are *Eucalyptus* hybrid (locally known as Safeda), *Grewia optiva* (Bhimal), *Bauhinia purpurea* (Kachnar), *Morus alba* (Shahtoot) and *Melia azedarach* (Bakain). Except for bamboo, *Eucalyptus* and *M. azedarach* which have timber value for rural needs, the other species are prized fodder species of the region. *Morus alba* is also used for feeding silk worms.

Litter fall and nutrient dynamics

Litter production was measured in litter trays with nylon mesh bottom for one year (September 1995–August 1996) with five trays being placed randomly in each plantation. Monthly estimation was made by collecting the litter and sorting it into leaves, twigs and bark. We used only leaf litter for further determinations, since twig and bark litter were in very insignificant quantities. The leaf litter was oven dried at 80 °C until constant weight and analysed for N (Piper 1966) by the di-acid digestion method and titration with N/10 NaOH and methyl red as indicator, P by blue colour development and measuring transmission colorimetrically at 600 nm (Olsen *et al.* 1954), K by flame photometer (Jackson 1973) and Ca and Mg by titrating filtrate against 0.02 N EDTA (Cheng & Bray 1951).

The nutrient retranslocation in the leaves during senescence was estimated using nutrient:Ca ratios, assuming that Ca is relatively much less mobile or practically immobile (Vitousek & Sanford 1986):

$$\text{translocation } (\%) = \left(1 - \frac{x}{y}\right) 100$$

where

x = nutrient concentration in leaf litter/maximum Ca concentration in leaf litter and

y = nutrient concentration in green leaf/maximum Ca concentration in green leaf

To study the residence time (Tn) and fractional annual turnover of nutrients, three replicates of forest floor material consisting of the LFH zone (L = undecomposed litter layer, F = partially decomposed litter layer, H = humus layer) were sampled in the month of October 1996 from the six stands using 1 × 1 m quadrats and their nutrient content estimated. Tn and the fractional annual turnover rate (Reiners & Reiners 1970) were calculated as:

$$\text{Tn} = \frac{\text{Forest floor nutrient pool}}{\text{Annual litter fall nutrients}}$$

$$\text{Fractional annual turnover rate} = \left(\frac{1}{\text{Tn}}\right) \times 100$$

Leaf litter decomposition

Litter decomposition studies were carried out by the nylon bag technique, using bags of size 20 × 20 cm, each containing 20 g freshly fallen air-dried senescent leaves. Fifteen bags were placed in each stand in March 1996 and three bags each were randomly retrieved in May, August and November the same year and in February in the following year. The leaves were washed free of all attached soil particles over a fine sieve, oven dried at 80 °C and estimated for dry weight. A decay constant (k) and time required for loss of 50 and 95% of the original dry weight was estimated using Olson's model (1963).

Soil analysis

Soil samples were collected in October 1996 by hand-driven augers from three depths (A = 0–7.5 cm, B = 7.5–15 cm, C = 15–30 cm). Five soil samples from each depth were collected, and composite samples were prepared. Soil samples were air dried, sieved through 2-mm mesh and analysed for pH (1:2.5), percentage of water holding capacity (WHC), percentage of organic carbon (OC), percentage of total N, and available P and K by standard laboratory techniques (Jackson 1958, Piper 1966).

Results

Litter dynamics

Leaf litter production from the six tree species are presented in Table 2 and the annual litter production and nutrients returned in the six forest plantations are given in Table 3.

The litter fall pattern was compared between the six plantations. Leaf fall in *Eucalyptus, M. azedarach, M. alba, B. purpurea* and *G. optiva* largely occurred between September and December, peaking in October for *B. purpurea* and in September

Table 2 Leaf litter production from six plantations raised on gravelly flood plains in the lower Western Himalayas

Month	Leaf litter production ($kg\ ha^{-1}$) Species					
	Eucalyptus	*Bauhinia purpurea*	Bamboo	*Grewia optiva*	*Morus alba*	*Melia azedarach*
September 1995	800.0	122.0	600.0	78.0	120.0	850.0
October	68.6	1023.6	446.0	376.7	243.0	484.5
November	330.0	371.6	251.5	430.0	413.6	374.8
December	128.2	353.3	459.5	487.7	1301.0	444.4
January 1996	-	265.7	213.6	184.3	139.0	84.8
February	49.4	80.3	108.4	42.7	-	-
March	312.3	396.7	160.8	216.5	75.5	-
April	509.3	-	603.5	-	-	-
May	310.0	-	-	374.8	65.7	316.7
June	130.3	110.6	463.14	314.3	-	-
July	235.7	88.6	714.60	95.7	-	49.0
August	102.7	48.7	231.22	38.2	-	11.3
Total	2976.5 ± 213.87	2861.4 ± 276.38	4252.3 ± 194.36	2638.9 ± 156.72	2358.8 ± 409.57	2615.5 ± 262.22

- No litter fall occurred
± Standard deviation

Table 3 Leaf litter production and quantity of nutrients returned annually from six tree species raised on gravelly riverbed land

Species	Age (year)	Density (ha^{-1})	Average dbh (cm)	Litter production ($kg\ ha^{-1}\ year^{-1}$)	Nutrient returned ($kg\ ha^{-1}\ year^{-1}$)				
					N	P	K	Ca	Mg
Eucalyptus	14	2500	15.83	2976.46	36.14	10.85	4.47	79.43	15.42
G. optiva	11	2500	7.83	2638.88	40.28	5.56	2.77	64.15	15.96
B. purpurea	11	2500	8.78	2861.36	58.25	7.21	2.73	89.80	23.96
M. azedorach	9	2500	11.27	2615.50	55.30	5.56	2.90	61.98	13.62
M. alba	23	2000*	15.07	2358.76	66.14	4.64	4.86	65.16	23.74
Bamboo	-	-	14.53 **	4252.30	46.67	10.28	6.14	83.43	25.85

* Mortalities occurred in the plantation hence the lower density.
** Average dbh of culms

for *M. azedarach* and *Eucalyptus* (Table 2). In *G. optiva* litter fall was recorded regularly over the year except in April, with maximum production occurring in December. In *G. optiva* the leaves remained green throughout the winter and leaf fall largely occurred during the summer months (April–June), reaching a high 374.8 kg ha^{-1} in May. In *M. alba* the peak was recorded in December (1301.8 kg ha^{-1}) and least in May. In the mixed bamboo plantation, litter production peaked in July (714.6 kg ha^{-1}) with higher quantities of leaf litter matching fluxes of leaf flushes that occurred in the preceding months.

The highest leaf fall was recorded in bamboo plantation (4.25 t ha^{-1}) followed by *Eucalyptus* (2.97 t ha^{-1}) and *B. purpurea* (2.86 t ha^{-1}). The litter fall for the other three species ranged between 2.61 and 2.86 t ha^{-1} (Table 3). There were significant variations in the quantities of nutrients returned to the plantation floor by leaf litter in the course of a year. The highest amount of annual nitrogen (N) was returned from *M. alba* (66.14 kg ha^{-1}) followed by *B. purpurea* (58.25 kg ha^{-1}). The least quantity was returned from *Eucalyptus* (36.14 kg ha^{-1}). Phosphorus (P) return was highest in *Eucalyptus*, followed closely by bamboo. While the quantities of potassium (K) returned to the soil by all six species remained low, calcium (Ca) quantities were returned in much larger quantities. The highest amount of Ca was returned by *B. purpurea* (89.8 kg ha^{-1} $year^{-1}$) followed by bamboo (83.43 kg ha^{-1} $year^{-1}$) and *Eucalyptus* (79.43 kg ha^{-1} $year^{-1}$). Magnesium (Mg) was returned in much larger quantities when compared with P and K, with the highest quantity being returned by the bamboo species. The order of nutrient returned to the forest floor was: Ca > N > Mg > P > K for all species except *M. alba* where the trend was N > Ca > Mg > K > P.

Nutrient retranslocation

There were significant variations in the concentrations of leaf litter nutrients across the period of observation. In general, nutrient concentration was greater in deciduous species than in evergreen species like *Eucalyptus* and bamboo. In bamboo, the N concentration remained more or less constant except for a peak in February when N concentration was 2.04%. Fluctuations were recorded for all other elements that peaked in different months – P in June, K and Ca in December and April respectively and Mg in September. Ca concentration in *Eucalyptus* remained at about 3% except for a peak in June. N concentration fluctuated widely (0.56–2.82%) in *Eucalyptus* and Mg concentration reached a peak in July (2.10%).

In deciduous species, fluctuations in the concentrations of N and Mg in leaf litter were significant. In *M. alba*, N concentration was 2.1% in September but increased to 3.4% in December. An increase in K and Mg concentrations were also recorded during this month, which was the time when the highest leaf fall was recorded. P concentration peaked in May. In *B. purpurea*, N concentration declined in the first two months, increased in November and peaked in January (3.45%), after which it declined. P concentration was more or less constant from September to March and peaked in June (1.40%). Mg concentration was highest in September after which it ranged between 0.3 and 0.9% in October to March and then increased to 1.5% in June. Ca concentration increased from 1% in September to 4% in October and November, after which the values remained low (1.0–3.5%). No litter fall was recorded in *M. azedarach* for four months (February–April, June). Concentration of N fluctuated over the study period although not much variation was recorded for P and K. P and Mg concentration increased to 0.86 and 1.5% respectively in July.

N concentration in *G. optiva* showed a fluctuating trend decreasing from 1.51 to 1.09% from September to November and then increasing to 3.1% in January. Concentration of P in leaf litter was highest (1.1%) in July, while that of K was highest in May (0.18%). Ca concentration declined from 4% in September to 3% in February and increased to 4% in June. Mg concentration peaked to 1.2% in July.

The extent of translocation of N, P and K varied between species (Table 4). Maximum retranslocation of N occurred in *M. alba* where 84% of the N was reabsorbed into the woody component and least in bamboo where only 16.5% of N was retranslocated. P was absorbed back to an extent of 70.2% in *M. alba* and least in *M. azedarach* (22%). K, a highly mobile element, was retranslocated into the woody biomass to an extent of 77.8% in *M. azedarach.*

Table 4 Percentage nutrient retranslocation in the six tree species

Species	Period of senescence*	Nutrients (%)**		
		N	P	K
Grewia optiva	May (374.6)	81.4 (305)	37.0 (138.6)	30.2 (0)
Eucalyptus	April (509.3)	68.2 (347.3)	57.5 (292.8)	50.6 (257.7)
Bauhinia purpurea	October (1023.6)	45 (460.6)	29.0 (296.8)	43.5 (445.2)
Melia azedarach	November (374.8)	68 (254.8)	22 (84.2)	77.8 (291.6)
Morus alba	October (242.8)	84 (204)	70.2 (170.4)	63 (153)
Bamboo	April (603.5)	16.5 (99.5)	42.5 (546.1)	64.7 (390.4)

* Values in parentheses are the leaf litter production in that particular month.
** Values in parentheses show the amount (kg ha^{-1}) of nutrients (N, P, K) retranslocated during the month.

Leaf litter nutrient concentration vs. leaf fall

A negative correlation for leaf litter and N was observed in *Eucalyptus, G. optiva, M. azedarach* and bamboo (Table 5). For P the correlation was negative in *G. optiva, B. purpurea, M. alba,* bamboo and *M. azedarach.* Retranslocation of Mg occurred in *Eucalyptus, B. purpurea, M. azedarach* and bamboo. However, the correlation was insignificant with regard to all of the elements studied (N, P, K, Ca, Mg) and this could be attributed to errors that might have occurred during the analysis of tissue samples.

Table 5 Correlation coefficients (r) between monthly leaf fall (log x) and nutrient concentration (y) and their regression equations of the form y = a + b log x

Species	Element	r value	Equation	Standard error
Eucalyptus	N	- 0.4817	y = 2.6928 – 0.4078 log x	0.6698
	P	0.0927	y = 2.0888 + 0.1894 log x	0.7610
	K	0.3713	y = 1.7941 + 2.8486 log x	0.3713
	Ca	0.2667	y = 1.6798 + 0.1953 log x	0.2667
	Mg	- 0.1204	y = 2.2657 – 0.1613 log x	0.7588
Grewia optiva	N	- 0.1882	y = 2.4137 – 0.1023 log x	0.4203
	P	0.0498	y = 2.2612 – 0.0579 log x	0.4274
	K	0.1466	y = 2.0793 + 1.6336 log x	0.4233
	Ca	0.3738	y = 2.7198 + 0.1805 log x	0.3969
	Mg	- 0.3006	y = 2.2118 + 0.0506 log x	0.4276
Bauhinia purpurea	N	- 0.3006	y = 1.8217 + 0.1661 log x	0.3292
	P	0.2785	y = 2.2613 – 0.2056 log x	0.3315
	K	0.2804	y = 1.9552 + 0.2804 log x	0.3313
	Ca	0.4832	y = 1.8519 + 0.1363 log x	0.3022
	Mg	- 0.3367	y = 2.3242 – 0.1379 log x	0.3250
Morus alba	N	- 0.1643	y = 2.0250 + 0.1079 log x	0.4944
	P	0.5104	y = 2.4875 – 0.5861 log x	0.4310
	K	0.1121	y = 2.4232 – 0.7520 log x	0.4980
	Ca	0.5047	y = 1.1197 + 0.4460 log x	0.4327
	Mg	- 0.2959	y = 2.0487 + 0.3385 log x	0.4787
Melia azedarach	N	- 0.2858	y = 3.3634 – 0.4970 log x	0.6579
	P	0.6299	y = 2.7891 – 1.6962 log x	0.5332
	K	0.2168	y = 1.8979 + 3.2811 log x	0.6702
	Ca	0.6738	y = 1.0416 + 0.5791 log x	0.5073
	Mg	- 0.4978	y = 2.8051 – 0.7705 log x	0.5954
Bamboo	N	- 0.7076	y = 3.0759 – 0.4540 log x	0.1987
	P	0.3930	y = 2.3776 – 0.6824 log x	0.2587
	K	0.3265	y = 2.7850 – 1.7643 log x	0.2659
	Ca	0.1771	y = 2.4169 + 0.0538 log x	0.2769
	Mg	- 0.0240	y = 2.5313 + 0.0178 log x	0.2812

Leaf litter decomposition and decomposition constants

Decomposition of confined leaf litter occurred rapidly in the case of *G. optiva* and *M. alba* followed by *M. azedarach, B. purpurea, Eucalyptus* and bamboo (Table 6). The results for dry weight loss, decomposition constant (k) and half-life ($t_{0.50}$) revealed that decomposition was rapid in *G. optiva* and *M. alba* in comparison with other species (Table 7). In *G. optiva* 71% of the original dry weight was lost in one year, while in *M. alba* 68% was lost; accordingly their k values were 1.2347 and 1.1318 respectively. For the remaining four species, the values ranged between 0.6144 and 0.7330. Decomposition of leaf litter of bamboo and *B. purpurea* was slowest, with only half of the initial dry weight decomposing in one year.

Table 6 Dry weight loss (g) of confined leaf litter of six tree species raised on gravelly flood plains in the lower Western Himalayas

Species	May	August	November	February	% C V (across months)	Exponential function	r^2
Eucalyptus	15.61 ± 0.40	13.93 ± 0.06	12.37 ± 0.90	10.82 ± 0.40	4.683	$Y = 17.712\ e^{-0.0406x}$	0.9986
M. alba	7.22 ± 0.28	7.38 ± 0.27	6.41 ± 0.46	6.45 ± 0.76	8.173	$Y = 7.723\ e^{-0.016x}$	0.7024
Bamboo	13.02 ± 0.29	13.37 ± 0.60	11.44 ± 0.43	10.01 ± 0.63	4.90	$Y = 15.047\ e^{-0.0315x}$	0.8399
B. purpurea	14.62 ± 0.33	12.23 ± 1.40	11.60 ± 0.42	9.96 ± 0.54	7.60	$Y = 22.957\ e^{-0.1099x}$	0.7778
G. optiva	13.64 ± 1.24	6.95 ± 0.54	6.66 ± 0.40	5.82 ± 0.63	10.80	$Y = 14.905\ e^{-0.0866x}$	0.7732
M. azedarach	10.74 ± 0.43	12.64 ± 1.50	9.87 ± 0.40	9.61 ± 0.72	9.51	$Y = 12.317\ e^{-0.0194x}$	0.3687

± SD

Table 7 Leaf litter decomposition and decomposition constants for six tree species growing in gravelly flood plains in the Doon Valley

Species	Initial weight (g)	Dry weight remaining after 1 year	Dry weight lost (%)	k value	Half-life (0.693/k) ($t_{0.5}$)	3/k ($t_{0.95}$)
Eucalyptus	20	10.82 ± 0.40	46	0.6144	1.128	4.883
M. alba	20	6.45 ± 0.76	68	1.1318	0.612	2.6506
B. purpurea	20	9.96 ± 0.54	50	0.6973	0.993	4.302
Bamboo	20	10.01 ± 0.63	50	0.6922	1.001	4.334
G. optiva	20	5.82 ± 0.63	71	1.2347	0.561	2.430
M. azedarach	20	9.61 ± 0.72	52	0.7330	0.945	4.092

± SD

Plantation floor nutrient mobility

The forest floor nutrient mass (LFH zone) from the six plantations is shown in Table 8. Ca levels in the forest floor were highest in *B. purpurea* and lowest in *M. azedarach*. Surprisingly, Mg content was higher than N, P, K contents in *G. optiva*, *B. purpurea* and bamboo plantation floors. The relative abundance of these nutrients were Ca > Mg > N > P > K in *G. optiva*, *Eucalyptus*, *B. purpurea* and bamboo, Ca > N > Mg > K > P in *M. alba* and Ca > N > Mg > P > K in *M. azedarach*.

Tn was generally high in *G. optiva* for all elements except P and K (Table 9). Tn of P was highest in bamboo and of K in *M. azedarach*. The mobility of different elements (calculated as fractional annual turnover) was K > P > N > Ca > Mg in *G. optiva*, P > N > K > Ca > Mg in *Eucalyptus*, N > P > K > Ca > Mg in *B. purpurea*, N > Mg > P > K > Ca in *M. alba*, N > Ca > P > K > Mg in *M. azedarach* and N > K > Ca > P > Mg in bamboo plantation.

Plantation floor characteristics

The results of the soil analysis carried out in samples collected from the six plantations are given in Table 10. No consistent trend was recorded with regard to changes in soil pH in different species because of the nature of the deposited material at the six sites. Improvements were noticed with regard to WHC in stands of *Eucalyptus*, *G. optiva*, *M. alba* and in bamboo where there were some changes in the top soil layer (0–7.5 cm depth). Higher values in the *M. azedarach*

Table 8 Nutrient content of the plantation floor (LFH zone) in six tree species in the Doon Valley

Species	Nutrient content (kg ha^{-1})				
	N	P	K	Ca	Mg
Grewia optiva	59.12	7.20	3.53	142.00	121.82
Eucalyptus	40.60	11.78	7.63	201.20	44.36
Bauhinia purpurea	63.14	9.60	4.56	260.40	88.80
Morus alba	78.48	8.22	9.16	127.20	37.92
Melia azedarach	73.12	9.40	6.44	102.30	32.20
Bamboo	56.70	22.11	9.70	175.84	109.20

Table 9 Residence time (Tn) and fractional annual turnover of nutrient leaf litter in six tree plantations

Species	Residence time (year)					Fractional annual turnover (%)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Grewia optiva	1.467	1.294	1.274	2.213	7.632	68.16	77.27	78.50	45.18	13.10
Eucalyptus	1.123	1.085	1.707	2.533	2.876	89.04	92.16	58.58	39.47	34.77
Bauhinia purpurea	1.083	1.331	1.670	2.900	3.700	92.33	75.13	59.88	34.48	27.02
Morus alba	1.186	1.767	1.884	1.952	1.597	84.31	56.60	53.07	51.22	62.61
Melia azedarach	1.331	1.690	2.220	1.650	2.364	75.13	59.17	45.04	60.60	42.30
Bamboo	1.215	2.150	1.580	2.107	4.224	82.30	46.51	63.30	47.62	23.67

block were caused by the peculiarity of the site which was in a depression and led to the settling down of sediments. OC levels were, however, much better in stands of *Eucalyptus*, *M. azedarach* and *M. alba*. Levels of total N percentage and available P were much higher in stands of *Eucalyptus*, *M. azedarach* and *G. optiva* plantations.

Table 10 Modification of soil properties and nutrient availability under different tree stands

Stand	Depth (cm)	pH	WHC (%)	OC (%)	Total N (%)	Available P (ppm)	Available K (ppm)
Grewia optiva	A	6.5	50.38	3.10	0.48	430	18.6
	B	6.0	48.50	0.86	0.14	115	6.12
	C	6.0	49.00	0.80	0.08	75	3.34
Eucalyptus	A	6.8	42.23	1.23	0.14	105	8.56
	B	6.5	44.40	0.62	0.07	90	3.34
	C	6.5	45.60	0.55	0.07	65	5.56
Bauhinia purpurea	A	7.0	51.55	1.35	0.12	200	15.8
	B	6.5	48.31	0.73	0.09	70	5.56
	C	6.5	49.70	0.62	0.04	65	8.04
Morus alba	A	6.7	68.08	2.04	0.21	245	42.22
	B	7.0	60.14	1.02	0.12	135	20.0
	C	7.0	61.44	0.90	0.11	100	16.20
Melia azedarach	A	6.7	59.50	2.16	0.25	250	29.7
	B	6.5	46.70	0.80	0.09	115	13.0
	C	6.2	47.10	0.72	0.07	65	13.0
Bamboo	A	7.0	47.00	1.40	0.17	135	20.5
	B	7.0	36.40	0.90	0.08	75	18.6
	C	7.0	39.00	0.45	0.05	60	11.6
Control site	A	6.3	44.57	0.64	0.41	200	11.5
	B	6.7	43.47	0.62	0.06	380	18.0
	C	6.0	44.60	0.58	0.05	180	10.0

WHC = water holding capacity, OC = organic carbon
A = 0–7.5 cm, B = 7.5–15 cm, C = 15–30 cm soil depth

Discussion

Litter fall in forest plantations is an indicator of leaf turnover rate, which is determined by leaf phenology that is influenced by environmental and genetic factors. At this site leaf litter production among five species were nearly similar, excluding that from bamboo where leaf litter production was nearly twice that of other species. Tripathi and Singh (1994) reported a litter fall of 7.18 t ha^{-1} $year^{-1}$ from mature bamboo (*D. strictus*) stands, with leaf litter accounting for 64% of the litter production. In our study, peak leaf fall in five species occurred from September to December, while as for bamboo, the leaf fall was highest in July. It appeared that under the existing site conditions the roots of all the tree species had become well established and were able to forage for moisture and nutrients below the deposited debris layers. At the same time the roots reduced energy losses by cutting down on foliage loss by regular leaf fall.

This phenomenon was not evident in bamboo where leaf fall was observed regularly over the year except in May when shoots were leafless and 603.5 kg ha^{-1} of leaf litter was recorded in the preceding month. With the arrival of the monsoon in June and the emergence of a new flush, leaf fall increased and peaked to 714.6 kg ha^{-1} in July. Since bamboo rhizomes are not sufficiently deep, the species experienced a stressed period in the summer leading to complete loss of foliage.

Internal recycling of N, P, K was pronounced in all species, except for N in bamboo and *B. purpurea*; the latter being a N-fixing species, and the former, with a high root turnover, was able to replenish its normal requirements from the soil system. In *D. strictus* plantations, a rapid turnover of live roots, which are relatively rich in N and P, has been reported (Tripathi & Singh 1994). This high return to soil by fine roots followed by litter fall may serve as a defense against volatilisation losses of N and P. High nutrient retranslocation has been observed to be more common in nutrient poor sites (Chapin 1980, Singh *et al.* 1984).

In deciduous species like *G. optiva, M. alba, M. azedarach* (which produce the entire foliage every year) higher quantities of N and P were reabsorbed because the acquisition from soil layers by active absorption is costlier than carbon (Bloom *et al.* 1985). Besides, nutrient resorption patterns can vary widely between species and also in their extent (Tilton 1978, Ostman & Weaver 1982). Whittaker *et al.* (1979) and Singh *et al.* (1984) have suggested that elements normally in short supply (N, P) are redistributed prior to senescence. This process accelerates during the weeks prior to the formation of abscission layers.

Retranslocation of P in the six species studied (22–57%) is within the range reported by Chapin & Kedrowski (1983) except in case of *M. alba* where 70.2% of P was retranslocated during the period of senescence. High nutrient resorption efficiency is dependent on several factors, including the relative pool size of mobile and insoluble nutrients (Aerts 1996) and also the existence of a nutrient sink. Soil moisture availability may also be an important factor (del Arco *et al.* 1991) for a place experiencing continued dry spell and having xeric sites; many species shed their leaves much earlier or beyond their normal period of leaf fall (Raizada & Srivastava 1986).

Weight loss from confined leaf litter was more rapid in deciduous species than evergreen species with a maximum of nearly 70% weight loss in one year. Accordingly their half-life was between 0.56 and 0.94 (Table 7). Initial N and P contents in senescent leaves and constituents of cell wall affect weight loss and decomposition rates, which decline as microbial biomass builds up. Leaves of *B. purpurea, Eucalyptus* and bamboo with higher amounts of cellulose and lignin are more resistant to decay (Waring & Schlesinger 1985). In studies carried out in sal (*Shorea robusta*) and *E. camaldulensis* plantations at Dehra Dun, it was reported that the lignin content in leaves of the former was 4.24%, this value was higher than that of the latter (3.65%), showing that sal litter decomposed slower than *Eucalyptus* (Bahuguna *et al.* 1990). The increase in Ca concentration with the increase in leaf age results from secondary thickening, including calcium pectate deposition in cell walls, and from increasing storage of calcium oxalate in cell vacuoles.

This slow rate of decomposition in *B. purpurea*, *Eucalyptus* and bamboo resulted in the accumulation of higher amounts of Ca in the plantation floor (Table 8). In contrast to this, stands with species having 'soft' senescent leaves (*G. optiva*, *M. alba*, *M. azedarach*) experienced rapid decomposition that led to higher N, P and Mg levels on the floor, lower residence time and higher annual turnover rates for these three elements (Table 9).

The impact of these six plantations on soil properties at different depths have undergone slight modification especially in the 0–7.5 cm layer, although statistical analysis revealed that the changes cannot be attributed singularly to any one species. Under natural conditions, impact of a particular species on soil properties occurs over a longer time scale and significant improvements at the site are not expected within two decades.

In conclusion, evergreen and deciduous tree species raised on gravelly flood plains in the subhumid regions, demonstrated efficient use of nutrients through internal cycling and returns of leaf litter, which decomposed rapidly and released nutrients for further reabsorption. On a longer time scale, these sites, using appropriate silvicultural techniques, could be brought back to improved and efficient land-use practices.

Acknowledgements

The authors are grateful to the Director of the Institute and the Head of Division for providing necessary facilities, to R. S. Chettri for field support and S. Kumar for secretarial assistance. This paper is authorised for publication as a research paper by the Director, Central Soil and Water Conservation Research and Training Institute, Dehra Dun (Uttaranchal), India, as contribution No 640/22/2000.

References

AERTS, R. 1990. Nutrient use efficiency in evergreen and deciduous species from heath lands. *Oecologia* 84: 391–397.

AERTS, R. 1996. Nutrient resorption from senescing leaves of perennials : are there general patterns? *Journal of Ecology* 84: 597–608.

AERTS, R. & VAN DER PEIJL, M. J. 1993. A simple model to explain the dominance of low productive perennials in nutrient-poor habitats. *Oikos* 66: 144–147.

BAHUGUNA, V. K., NEGI, J. D. S., JOSHI, S. R. & NAITHANI, K. C. 1990. Leaf litter decomposition and nutrient release in *Shorea robusta* and *Eucalyptus camaldulensis* plantation. *Indian Forester* 116(2): 103–114.

BHARDWAJ, S. P. & SINGH, P. N. 1981. *Soils, Land Capability and Land-use Characteristics of Soil Conservation Research Farm, Dehra Dun.* Bulletin No.7-14/D-11. Dehra Dun. 23 pp.

BLOOM, A. J., CHAPIN, F. S. III & MONNEY, H. A. 1985. Resource limitation in plant: an economic analogy. *Annual Review of Ecology and Systematics* 16: 363–392.

CHAPIN, F. S. III. 1980. Mineral nutrition of wild plants. *Annual Review of Ecology and Systematics* 11: 233–260.

CHAPIN, F. S. III. & KEDROWSKI, R. 1983. Seasonal changes in nitrogen and phosphorus fractions and autumn retranslocation in evergreen deciduous taiga trees. *Ecology* 64: 376–391.

CHARLEY, J. R. & RICHARDS, B. N. 1983. Nutrient allocation in plant communities, mineral cycling in terrestrial ecosystems. Pp. 5–45 in Lang, O. L., Bobel, P. S., Osmond, C. B. & Ziegler, M. (Eds.) *Physiological Plant Ecology IV.* Springer, Berlin.

CHENG, K. L. & BRAY, R. H. 1951. Determination of calcium and magnesium in soil and plant material. *Soil Science* 72: 449–458.

DAS, A. K. & RAMAKRISHNAN, P. S. 1985. Litter dynamics in khasi pine (*Pinus kesiya* Royle ex Gordon) of north-eastern India. *Forest Ecology and Management* 10: 135–153.

DEL ARCO, J. M., ESCUDERO, A. & GARRDO, M. V. 1991. Effects of site characteristics on nitrogen retranslocation from senescing leaves. *Ecology* 72: 701–708.

GRIME, J. P. 1979. *Plant Strategies and Vegetation Processes.* Wiley, Chichester.

JACKSON, M. L. 1973. *Soil Chemical Analysis.* Prentice Hall of India Pvt. Ltd., New Delhi. 478 pp.

MEENTEMEYER, V., BOX, E. O. & THOMPSON, R. 1982. World patterns and amounts of terrestrial plant litter production. *Bio-Science* 32: 125–128.

OLSEN, S. R., COLE, C. V., WATANABE, F. S. & DEAN, L. A. 1954. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate.* Circular USDA 939. 19 pp.

OLSON, J. S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. *Ecology* 44: 322–331.

OSTMAN, N. L. & WEAVER, G. T. 1982. Autumnal nutrient transfer by retranslocation, leaching and litter fall in a chestnut oak forest in southern Illinoss. *Canadian Journal Forest Research* 12: 40–51.

PIPER, C. S. 1966. *Soil and Plant Analysis.* Hans Publishers, Bombay. 368 pp.

RAIZADA, A. & SRIVASTAVA, M. M. 1986. Litter production in a *Populus deltoides* Marsh. plantation. *Forest Ecology and Management* 15: 215–218.

RAIZADA, A. & SRIVASTAVA, M. M. 1991. Nutrient accumulation in standing crop and returns through litter fall in a *Populus deltoides* Marsh. plantation. *Van Vigyan* 29(4): 192–199.

REINERS, W. A. & REINERS, N. M. 1970. Energy and nutrient dynamics of forest floors in three Minnesota forests. *Journal of Ecology* 58: 497–519.

SETH, S. K., KAUL, O. N. & GUPTA, C. 1963. Some observations on nutrient cycle and return of nutrients in plantations of New Forest. *Indian Forester* 89: 90–98.

SHARMA, S. C. & PANDE, P. K. 1989. Patterns of litter nutrient concentration in some plantation ecosystems. *Forest Ecology and Management* 29: 151–163.

SINGH, J. S., RAWAT, Y. S. & CHATURVEDI, O. P. 1984. Replacement of oak forests with pine in the Himalayas affects the nitrogen cycle. *Nature* 311: 54–56.

SRIVASTAVA, P. B. L., KAUL, O. N. & MATHUR, H. N. 1972. Seasonal variation of nutrients in foliage and their return through leaf litter in some plantation ecosystems. Pp. 66–72 in *Proceedings of Symposium on Man-Made Forests in India.* Society of Indian Foresters, Dehra Dun.

TILTON, D. L. 1978. Comparative growth and foliar element concentration of *Larix laricina* over a range of wetland types in Minnesota. *Journal of Ecology* 66: 499–512.

TRIPATHI, S. K. & SINGH, K. P. 1994. Productivity and nutrient cycling in recently harvested and mature bamboo savannas in the dry tropics. *Journal of Applied Ecology* 31: 109–124.

VITOUSEK, P. M. & SANFORD, R. L. JR. 1986. Nutrient cycling in moist tropical forest. *Annual Review of Ecology and Systematics* 17: 137–167.

WARING, R. H. & SCHLESINGER, W. H. 1985. Decomposition and forest soil development. Pp. 181–210 in *Forest Ecosystems: Concepts and Management.* Academic Press Inc., London.

WHITTAKER, R. H., LIKENS, G. E., BORMAN, H., EATON, J. S. & SICCAMA, T. G., 1979. The Hubbard Brook Ecosystem Study: forest nutrient cycling and element behaviour. *Ecology* 60: 203–220.