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Structure and function of oak forest ecosystem of north - eastern India
II. Nutrient dynamics

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Abstract. This paper deals with nutrient concentration, standing state, uptake, return, turnover time, release and nutrient cycling in the dominant oak tree species of *Quercus dealbata*, *Quercus fenestrata*, *Quercus griffithii* and *Rhododendron arboreum* in two oak forest sites. Biomass dynamics and net primary productivity have been dealt in earlier paper. In these oak forest sites, the soil, tree layer and litter accounted for 65-97.82, 1.44-32.60 and 0.04-1.39 per cent of the total nutrient in the system. The concentration of nutrients in the tree species were in the order: leaf > twig > branch > bole. The compartmental distribution of standing state of nutrients in the tree layer were in the order: bole > leaf > branch > twig. The uptake of nutrients by vegetation in the two oak forest sites were 13.31-20.16 N, 12.97-16.38 P, 13.05-19.16 K and 10.11-17.41 Na per cent of the total standing state. Out of the total uptake 11.49-17.31 N, 14.99-17.52 P, 11.52-13.83 K and 5.68-10.96 Na per cent were released through the decomposition. Turnover time on standing state for different nutrients varied from 4.98-7.79 years. Turnover time and rate for various nutrients on forest litters ranged from 1.50-1.69 years and 0.58-0.66 in both forest sites. Nutrient use efficiency was higher for sodium and phosphorus in both the forest sites in comparison to nitrogen and potassium.

Key words: Nutrient concentration, standing state, uptake, nutrient return, turnover time, nutrient use efficiency

Introduction

Nutrient is considered as one of the unifying feature in understanding the functioning of an ecosystem. Knowledge of nutrient cycling in forest ecosystem is pre-requisite for high and sustained production and to determine the evolution of the ecosystem. Nutrient accumulation and cycling of nutrients between soil and vegetation in several oak forests have been evaluated (Johnson and Risser 1974; Rochow 1975; Monk and Day 1985). In India Singh and Singh (1986) and Rawat and Singh (1988) have recently reviewed the work done on the nutrient dynamics in the oak forests in Central Himalayas. However, there is no report on the nutrient dynamics in the oak forests from eastern Himalayas. Therefore, the present study was conducted to evaluate the concentration, standing state, uptake, return, release, turnover and cycling of nutrients in two oak forests of Manipur, north eastern India.

Study site and climate

Study site, climate, biomass dynamics and net primary production of the present forests have been described in a related paper (Singh and Yadava 1994).

Material and methods

Samples of different tree components i.e. bole, branch, twig and leaf were collected from harvested trees of *Cinnamomum camphor*, *Gaultheria griffithiana*, *Neolitsea zeylanicum*, *Pyrularia edulis*, *Quercus dealbata*, *Quercus fenestrata*, *Quercus griffithii* and *Styrax serrulatum* in two forest site-I and *Alnus nepalensis*, *Lyonia ovalifolia*, *Quercus griffithii* and *Rhododendron arboreum* in forest site-II. Composite samples of each components (bole, branch, twig, leaf and fruit) of trees were brought to the laboratory and oven dried at 80°C. The oven dried samples were grinded to powder and stored for chemical analysis. Total nitrogen of three replication of biomass samples of different components from different tree species was determined by microkjeldahl method (Peach and Tracy 1956; Misra 1968). Organic carbon was determined by Walkley and Blacks rapid titration method. Phosphorus was determined by phosphomolybdic blue Colorimetric method (Jackson 1958). Potassium and Sodium were estimated by flame photometry (Jackson 1958). pH was determined in soil water suspension of 1.5 ratio using pH meter.

The amount of nutrients in each stratum (0-20, 20-40, 40-60, 60-80 and 80-100cm) of soil was estimated from bulk density, soil volume and nutrient concentration. The total nutrient content (kg ha-1) was estimated up to 1 m depth by adding the nutrient content of each depth.

The standing state of nutrient in the vegetation components was computed by multiplying dry weight of the components with their respective nutrient concentration. The values for standing state of nutrients in different components were assumed to obtain total nutrient storage in the vegetation. Nutrient uptake was computed by multiplying the value of net primary productivity of different components with

Components	N	P	K	Na
Cinnamomum camphor				
Bole	0.30±0.009	0.05±0.014	0.16±0.009	0.03±0.011
Branch	0.60±0.000	0.06±0.000	0.25±0.002	0.04±0.023
Twig	0.80±0.005	0.07±0.000	0.28±0.005	0.05±0.014
Leaf	1.20±0.000	0.11±0.009	0.45±0.014	0.07±0.000
Gaultheria griffithiana				
Bole	0.44±0.011	0.05±0.000	0.16±0.009	0.03±0.000
Branch	0.62±0.017	0.07±0.000	0.20±0.011	0.05±0.000
Twig	0.86±0.000	0.07±0.012	0.26±0.017	0.06±0.009
Leaf	1.60±0.011	0.11±0.009	0.54±0.011	0.09±0.011
Neolitsea zeylanicum				
Bole	0.70±0.014	0.05±0.005	0.25±0.018	0.03±0.018
Branch	0.82±0.014	0.06±0.000	0.28±0.018	0.04±0.005
Twig	0.90±0.009	0.06±0.005	0.32±0.000	0.04±0.000
Leaf	1.30±0.000	0.08±0.000	0.45±0.005	0.06±0.018
Pyrularia edulis				
Bole	0.55±0;009	0.05±0.000	0.32±0.028	0.03±0.000
Branch	0.61±0.011	0.05±0.005	0.35±0.011	0.03±0.000
Twig	0.74±0.000	0.06±0.005	0.43±0.005	0.04±0.000
Leaf	0.93±0.028	0.08±0.000	0.55±0.000	0.05±0.000
Quercus dealbata				
Bole	0.46±0.034	0.06±0.001	0.15±0.005	0.03±0.048
Branch	0.82±0.009	0.07±0.005	0.16±0.011	0.06±0.011
Twig	1.03±0.017	0.07±0.005	0.18±0.010	0.07±0.017
Leaf	2.60±0.023	0.12±0.028	0.52±0.017	0.08±0.023
Quercus fenestrata				
Bole	0.40±0.010	0.03±0.011	0.13±0.017	0.02±0.005
Branch	0.80±0.005	0.05±0.005	0.15±0.023	0.04±0.005
Twig	1.10±0.023	0.07±0.011	0.16±0.023	0.05±0.011
Leaf	2.20±0.011	0.15±0.011	0.31±0.023	0.09±0.011
Styrax serrulatum				
Bole	0.92±0.011	0.05±0.026	0.22±0.014	0.03±0.005
Branch	1.05±0.017	0.05±0.000	0.23±0.005	0.03±0.005
Twig	1.30±0.020	0.06±0.005	0.28±0.017	0.04±0.000
Leaf	1.75±0.000	0.09±0.014	0.40±0.000	0.05±0.000

Table 1. Concentration of nutrients (%±1 s.e.) in different components of tree species in forest site I.

Components	N	P	K	Na
Alnus nepalensis				
Bole	0.80±0.03	0.030±0.005	0.25±0.014	0.020±0.001
Branch	0.92±0.02	0.038±0.001	0.29±0.005	0.026±0.000
Twig	0.98±0.02	0.040±0.001	0.30±0.026	0.028±0.000
Leaf	1.40±0.03	0.050±0.001	0.45±0.004	0.035±0.001
Lyonia ovalifolia				
Bole	0.76±0.02	0.023±0.002	0.16±0.000	0.011±0.001
Branch	0.85±0.03	0.023±0.001	0.18±0.011	0.012±0.000
Twig	0.95±0.02	0.025±0.001	0.20±0.005	0.012±0.001
Leaf	1.20±0.01	0.030±0.002	0.25±0.014	0.016±0.001
Quercus griffithii				
Bole	0.64±0.09	0.019±0.001	0.16±0.020	0.010±0.001
Branch	0.80±0.03	0.022±0.001	0.17±0.026	0.012±0.001
Twig	1.10±0.01	0.030±0.001	0.22±0.023	0.016±0.001
Leaf	1.70±0.02	0.045±0.001	0.35±0.040	0.025±0.001
Rhododendron arboreum				
Bole	0.64±0.09	0.015±0.001	0.16±0.020	0.010±0.001
Branch	0.80±0.03	0.022±0.001	0.17±0.026	0.012±0.002
Twig	1.10±0.01	0.030±0.001	0.22±0.023	0.016±0.001
Leaf	1.68±0.02	0.045±0.001	0.35±0.040	0.025±0.000

Table 2. Concentration of nutrients (%±1 s.e.) in different components of tree species in forest site II.

their respective nutrient concentration. Litter samples collected from the litter traps at seasonal intervals on the two forest sites were pooled together in proportion of their weight to represent annual samples. The composite samples of leaf litter and miscellaneous litter were ground separately and analysed for nutrients. Return of nutrient to the forest floor was computed by multiplying the nutrient concentration of litter with the dry weight of litterfall. The release through litter was estimated from the data on litter decomposition. Turnover time of nutrient for different nutrients in standing vegetation was computed as the ratio, standing state/annual uptake. The turnover rate (K) for each element on the forest litter was calculated as K=A/(A+F) Chaturvedi and Singh (1987) where A is the amount of nutrients added to the forest litter by litterfall and F is the nutrient content of the lowest value of standing crop of litter in the annual cycle. Turnover time (t) is the reciprocal of the turnover rate (K). Nutrient use efficiency has been calculated as per g dry matter aboveground production (N PP) per g nutrient absorbed (uptake) in the forest community.

Results and discussion

Concentration of nutrients

The concentration of nutrients varied site to site and plant species to plant species. In trees concentration of all the nutrients (N,P,K and Na) was highest in leaf

	Site-I	Site-II
N	3.07	2.11
P	2.17	1.95
K	2.31	1.91
Na	2.45	2.02

Table 3. Factors by which the highest and lowest concentration differed among components species in site-I and site-II

followed by twig, branch and bole (Table 1 and 2). The concentration of nutrients (N,P,K and Na) in the forest site-I was slightly higher than that of forest site-II. The forest site-I was dominated by evergreen species of *Quercus dealbata* and *Quercus fenestrata* whereas site-II was dominated by deciduous species of *Quercus griffithii*. In the present study except for N the other estimated values were comparable with the values reported by Rawat and Singh (1988) in Central Himalaya oak forest. The concentration of nutrients considerably differ in plant tissues of different species. The factor by which the highest and lowest concentration differed in different species are given in Table 3. The magnitude of differences between the highest (in leaf) and lowest concentration (in bole wood) (2.9-4.3 for N, 2.2-7.2 for P, 3.0-4.1 for K and 2.1-5.5 for Na) were similar to those reported by Rawat and Singh (1988) and were much lower than those reported for trees of temperate forest. The amount of the various elements varied in different parts of the tree. For example, the leaf N was about 19.5 times more than phosphorus, 3.8 times more than K and 30.3 times more than Na. In twig N was 18.7 times more than P, 3.8 times more than K and 25.8 times from Na. In branch N was 17.3 times more than P, 3.5 times more than K and 25.5 time more than Na. In bole also N was 1.5 times, 3.11 times and 27.5 times more than P, K and Na respectively. Concentrations of nutrients in leaf litter and miscellaneous litter are summarised in Table 4 and 5. The concentration of nutrients in the litter was in the order of N > K > P > Na in both the sites.

Storage of nutrients

The concentration and content of nutrients in various soil depth (i.e. 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm) of forest site-I and site-II varied from depth to depth (Table 6 and 7). The total nutrient storage in the soil was in the order: N > K > Na > P.

The level of nutrients in the soil is governed by the amount of leaf fall and rate of litter decomposition in the natural system. The greater proportion of nutrients occured in the surface soil reflecting the massive input of nutrients to the soil through litterfall. Recently Laishram and Yadava (1988) have reported that from 41 to 82% of leaf litter was being decomposed and mineralized within a year in different tree species of the present forests. Concentration of nutrients (N,P,K and Na) were more in winter than in rainy season. The low concentration of nutrients in the rainy season partly may be owing to rapid downward movement with percolating water and partly because of rapid uptake of nutrients by vegetation for their luxuriant growth. Similar pattern of higher concentration of all nutrients in the surface soil has been reported in different forest ecosystems by several workers (Thompson, Black and Zoeliner

Species	N	P	K	Na
		Leaf litter		
Cinnamomum camphor	0.90±0.005	0.04±0.014	0.18±0.009	0.02±0.005
Gaultheria griffithiana	1.00±0.023	0.04±0.023	0.18±0.005	0.02±0.005
Neolitsea zeylanicum	0.86±0.017	0.07±0.023	0.16±0.011	0.05±0.005
Pyrularia edulis	1.22±0.005	0.06±0.001	0.25±0.017	0.03±0.011
Quercus dealbata	1.20±0.005	0.09±0.014	0.30±0.026	0.05±0.011
Quercus fenestrata	1.10±0.012	0.06±0.014	0.20±0.009	0.05±0.009
Quercus griffithii	1.00±0.014	0.08±0.017	0.21±0.023	0.04±0.005
Styrax serrulatum	1.06±0.020	0.06±0.023	0.22±0.018	0.04±0.017
		Miscellaneous		
	1.14±0.005	0.05±0.009	0.18±0.011	0.03±0.005

Table 4. Concentration (%±1 s.e.) in litterfall of Forest site-I

1954; Cunningham 1962; Panday and Kurvilla 1968; Kawahara and Tsutsumi 1972). The present values of nutrients in soil (0-20cm) were comparable with the values reported for tropical and temperate forests (Gotley *et al* 1975; Chaturvedi and Singh 1987).

The C:N ratio reflects the release of N into the soil from organic matter decomposition and therefore reflects the degree of decomposition of organic matter in the forest soil (Kononova 1966; Ulrich 1971). In both forest sites the maximum value of ratio (13:4) occured in the surface layers of soil (0.20cm) in the rainy season and minimum ratio (2:6) in winter.

Kawahara and Tsutsumi (1972) reported that the soil of forest stand attained steady state only when C:N ratio was 10. According to Pugh (1974) when C:N ratio approaches 10 an accelerated mineralisation process is indicated.

The total nutrient storage in the soil up to the depth of 1 m was 7,680 N, 228 P and 7,140 K and 3,360 Na Kg ha-1 in the study site-I whereas in the study site-II values were 7,776 N, 230.40 P, 6,240 K and 2,880 Na Kg ha^{-1}.

In the present study site-I except for N and P the other nutrients (K and Na) were found higher than the study site-II. Several workers have been studied the storage of nutrients in different ecosystems of the world (Cole, Gossel and Dice 1968; Cooper 1973; Kallio 1974; Johnson and Risser 1974; Foster and Morisson 1976; Van Cleave, Berney and Schlentner 1981). The present estimated values (0-20cm) were found lower than these reported values.

The values of various nutrients in the soil (0-20cm) reported in the present study are also lower than that of data reported from India by Rawat and Singh (1988) and Chaturvedi and Singh (1987) in oak and pine forests of Central Himalaya respectively.

Standing state of nutrients

The standing state of nutrients (N,P,K and Na) in various biomass components of the different constituent species in both forest sites was in the order bole > leaf > branch > twig and the total standing state of nutrients in the two forest sites was in the order N > K > P > Na (Table 8 and 9). This order agrees well with the pattern of nutrients in pine and spruce forests of the previous USSR (Rodin and Bazilevich 1967).

The total quantity of all nutrients (N,P,K and Na) in the aboveground components of tree layer was 1,390.23 N, 112.77 P, 365.83 K and 72.13 Na Kg ha^{-1} in the site-I whereas in the site-II it was to be 2,084.92 N, 65.99 P, 439.36 K and 42.22 Na Kg ha^{-1} respectively. Comparative account of standing state of nutrients in different oak forest ecosystems of the world is given in Table 10. The present estimated values were found higher than the reported values by Ovington (1962); Duvigneaud and Denaeyer De Smet (1970); Johnson and Risser (1974); Rochow (1975)(except K in Oklahama oak forest). The present values of standing state were slightly lower than the values reported by Rowat and Singh (1988) for the oak forest of Central Himalaya.

Nutrient uptake

The allocation of total uptake of nutrients (N,P,K and Na) in the constituent tree species of forest site-I and site-II was in the order: N, K, P, Na (Table 11). Generally trees retract the required nutrients from the soil in proportions that vary from species to species. Annual uptake of N, P, K and Na in the present study site-I was found a little higher than the study site-II.

Estimates of nutrient uptake in the temperate deciduous forest (Duvigneaud and Denaeyer-De Smet 1970; Nihlgard 1972; Johnson and Risser 1974) are 92-204 for N, 7-15 for P, 43-99 kg $ha^{-1}yr^{-1}$ for K. The uptake of K in the present study (57.35-69.92 kg ha^{-1}) fall within the above range but the uptake of N (277.58-279.56) and P (8.56-18.47 kg ha^{-1}) was found

Species	N	P	K	Na
		Leaf litters		
Alnus nepalensis	1.09±0.023	0.07±0.017	0.30±0.028	0.02±0.009
Lyonia ovalifolia	1.00±0.026	0.02±0.005	0.23±0.018	0.01±0.005
Quercus griffithii	1.10±0.005	0.06±0.009	0.22±0.011	0.03±0.005
Rhododendron arboreum	1.05±0.020	0.04±0.014	0.20±0.005	0.02±0.009
		Miscellaneous		
	1.05±0.001	0.06±0.023	0.16±0.011	0.01±0.005

Table 5. Concentration (%±1 s.e.) in litterfall of nutrients in litterfall of Forest site-II

FOREST SITE-I							
Deph (cm)	pH	Organic carbon	N	C:N	Available phosphorus	Exchangeable K	Na
0-20	5.96±0.011	2.65±0.021	0.26±0.009	10.19	0.007±0.004	0.20±0.014	0.11±0.016
20-40	6.10±0.015	1.35±0.007	0.19±0.017	7.09	0.006±0.009	0.17±0.011	0.09±0.017
40-60	6.40±0.019	0.96±0.021	0.16±0.020	6.00	0.006±0.009	0.15±0.021	0.07±0.021
60-80	6.67±0.015	0.53±0.022	0.13±0.014	4.08	0.006±0.007	0.13±0.018	0.05±0.013
80-100	6.80±0.017	0.29±0.022	0.09±0.011	0.31	0.003±0.000	0.11±0.013	0.04±0.010
			Content				
0-20			2400 (31.25)	67.20	67.20 (29.47)	1824 (25.68)	960 (28.57)
20-40			1824 (23.75)	57.60	57.60 (25.26)	1632 (22.97)	864 (25-71)
40-60			1440 (18.75)		43.00 (18.86)	1440 (20.27)	672 (20.00)
60-80			1152 (15.00)	15.09	34.40 (15.09)	1248 (17.57)	480 (14.29)
80-100			864 (11.25)		25.80 (11.32)	960 (13.51)	384 (11.43)
Total			7680		228.00	7104	3362

Table 6. Concentration (%±1 s.e.) and content of nutrient in forest soil (Values in the parantheses are the relative percentage of the total nutrients).

FOREST SITE-II							
Deph (cm)	pH	Organic carbon	N	C:N	Available phosphorus	Exchangeable K	Na
0-20	5.80±0.010	2.62±0.005	0.24±0.014	10.91	0.007±0.009	0.18±0.012	0.08±0.018
20-40	6.33±0.009	1.33±0.010	0.18±0.014	7.30	0.006±0.008	0.11±0.017	0.07±0.014
40-60	6.52±0.012	1.02±0.016	0.15±0.011	6.80	0.005±0.009	0.13±0.004	0.06±0.015
60-80	6.66±0.017	0.61±0.019	0.13±0.024	4.68	0.004±0.007	0.07±0.013	0.05±0.011
80-100	6.73±0.013	0.42±0.019	0.12±0.019	4.20	0.003±0.000	0.08±0.003	0.004±0.008
			Content				
0-20			2304 (29.63)		57.60 (25.00)	1728 (27.69)	768 (26.67)
20-40			1728 (22.22)		57.60 (25.00)	1536 (24.52)	672 (23.33)
40-60			1440 (18.52)		28.80 (12.50)	1248 (20.00)	576 (20.00)
60-80			1248 (16.05)		38.40 (16.67)	960 (15.38)	480 (16.67)
80-100			1056 (13.58)		48.00 (20.83)	768 (12.31)	384 (13.33)
Total			7776		230.40	6240	2880

Table 7. Concentration (%±1 s.e.) and content of nutrient in forest site-II (Values in the parantheses are the relative percentage of the total nutrients).

higher than those reported value for temperate deciduous forests. Rawat and Singh (1988) reported 184.7 kg N, 9.5 kg P, 51.7 kg K and 4.6 kg Na ha-1 in the oak forests in Central Himalaya.

The present values of nutrient uptake are also greater than those reported by Rawat and Singh (1988) for oak forest in Central Himalaya. Amount of nutrient uptake is usually directly proportional to the size of net primary production but the relationship varies for different forest communities (Rodin and Bazilevich 1967). Conifers extract N from the soil in the highest amount followed by Ca, K, Mg, P and Na respectively (Remezov and Pogrebnyak 1969) whereas oak forest extract highest amount of Ca followed by N, K, P and Na (Rawat and Singh 1968). In the present study sites the tree species extract highest amount of N followed by K, P and Na, however Ca was not estimated.

Nutrient return and release through litterfall

Litters are the main routs of nutrient return from aerial shoot to soil pool. The total input of nutrients via tree litterfall in the study site-I was 79.43 N, 4.82 P, 15.97 K and 2.70 Na kg ha^{-1} and the study site-II was 49.88 N, 2.47 P, 10.46 K and 1.02 Na kg ha $^{-1}$ (Table 12). In the temperate forest the annual return of N and P reported to range 14.1 and 125.0 and 1.7 and 10.0 kg ha^{-1} (Ovington 1959, 1965; Miller 1963a-c; Carlisle, Brown and White 1966; Kitazawa 1973; Denaeyer-De Smet and Duvingneaud 1973; Van Cleavs and Noonan 1975). The return of N and P in the tropical forests are reported to 18 and 72 and 0.3 and 28.0 kg ha^{-1} (Seth, Kaul and Gupta 1963; Singh 1968; Srivastava, Kaul and Mathur 1972). Rawat and Singh (1988) reported the total input of nutrients via tree litterfall: N, 75.8-124.6; P, 3.2-12.4; K, 12.7-23.6 and Na, 0.59-2.1 kg ha^{-1} yr^{-1} in oak forests in Central Himalaya and these reported values are higher than the present values except for Na.

Species	Nutrients N	P	K	Na
Cinnamomum camphor	90.47	11.07	44.05	6.56
Gaultheria griffithiana	45.01	4.50	15.18	3.52
Neolitsea zeylanicum	124.89	8.48	43.61	5.65
Pyrularia edulis	88.02	7.26	51.44	4.66
Quercus dealbata	453.94	39.86	109.61	24.22
Quercus fenestrata	229.92	15.81	12.89	12.25
Quercus griffithii	221.18	18.68	42.87	13.54
Components				
Bole	442.78 (31.84)	49.33 (43.74)	131.17 (35.85)	28.47 (39.47)
Branch	292.10 (21.01)	22.16 (19.65)	73.76 (20.16)	15.29 (21.19)
Twig	274.45 (19.74)	18.84 (16.70)	64.26 (17.56)	13.62 (18.88)
Leaf	380.90 (27.39)	22.44 (19.89)	96.64 (26.41)	14.75 (20.44)
Total	1390	112.77	365.83	72.13

Table 8. Standing state of nutrients (kg ha^{-1}) in different tree species and in total components of forest site-I (values in parentheses are the relative percentage of the total).

Species	Nutrients N	P	K	Na
Alnus nepalensis	486.22	18.74	152.73	12.86
Lyonia ovalifolia	192.36	5.02	40.43	2.61
Quercus griffithii	996.36	30.84	156.48	20.62
Rhododendron arboreum	409.98	11.39	89.72	6.13
Components				
Bole	679.06 (32.57)	20.10 (30.59)	137.98 (31.42)	12.4 (29.48)
Branch	415.06 (19.90)	14.55 (22.04)	94.19 (21.43)	9.99 (23.68)
Twig	392.73 (18.84)	13.43 (20.35)	87.09 (19.82)	9.28 (21.98)
Leaf	598.07 (28.69)	17.82 (27.02)	120.10 (27.33)	10.50 (24.86)
Total (standing state)	2084.92	65.99	439.36	42.22

Table 9. Standing state of nutrients (kg ha^{-1}) in different tree species and in total components of forest site-II (values in parentheses are the relative percentage of the total).

Of the total annual nutrient input through litterfall, the leaf litterfall accounted for 87.8-95% and miscellaneous litterfall accounted 4.9-12.1% in the present oak forest of Shiroy Hills. In the system of annual nutrient input about 75-85% was shared by leaf litterfall and 10-35% by wood litterfall (Klinge and Rodrigues 1968; Bernhard Reversat 1972). The values for nutrient input were recorded to be 81.3-85% through the leaf litterfall and 15-18.7% through wood litterfall (including miscellaneous litterfall) in oak forest of Central Himalaya (Rawat and Singh 1988). Pandey and Singh (1981) also reported about 80-83% and 17-20% of the total annual nutrient input through leaf litterfall and miscellaneous litterfall in oak conifers Kumaun Himalaya.

Nutrient release through litter decomposition

The release of nutrients (N, P, K and Na) through the decomposition of tree litterfall was 48.36 N, 2.76 P, 9.67 K and 1.38 Na in the study site-I and 31.90 N, 1.50 P, 6.62 K and 0.30 Na in the study site-II (Table 12). Of the total uptake in tree layer 17.31% N, 14.99% P, 13.83% K and 10.96% Na were releasing through leaf and miscellaneous litter in forest site-I and the total release in forest site-II was recorded to be 11.49% N, 17.52% P, 11.54% K and 5.68% Na annually.

Turnover time for nutrient in standing state

Turnover time for nutrients in the standing state

Forest	Location	N	P	K	Na	Reference
Quercus alba	Missouri	204	20	115	-	Rochow (1975)
Quercus robur	England	393	35	246	5	Ovington (1962)
Quercus robur - Carpinus betulus	Belgium	406	32	245	-	Duvigneaud and Danaeyer-De Smet (1970)
Quercus stellata - Quercus marilandica	Oklahoma	902	75	1093	-	Johnson and Risser (1974)
Oak	India	3300	135	965	79	Rawat and Singh (1988)
Oak Site-I	Manipur	1390.23	112.77	365.83	72.13	Present study
Oak Site-II	Manipur	2084.92	65.99	439.36	42.22	Present study

Table 10. Comparative account of standing state (kg ha^{-1}) of nutrients in tree layer of oak forests of the world.

Components	N	P	K	Na
	FOREST SITE-I			
Bole	35.04 (12.54)	3.51 (19.00)	11.89 (17.02)	2.04 (16.20)
Branch	29.95 (10.71)	2.29 (12.34)	7.18 (10.26)	1.82 (14.46)
Twig	32.32 (11.56)	2.20 (11.92)	7.10 (10.15)	1.80 (14.30)
Leaf	182.25 (65.19)	10.48 (56.74)	43.75 (62.57)	6.93 (55.04)
Total (Nutrient uptake)	279.56	18.47	69.92	12.59
	FOREST SITE-II			
Bole	58.10	1.74	12.95	1.05
Branch	38.53	1.34	8.65	0.92
Twig	38.76	1.31	8.48	0.90
Leaf	142.19	4.17	27.27	2.41
Total (Nutrient uptake)	277.58	8.56	57.35	5.28

Table 11. Uptake of nutrients (kg ha^{-1}) in different components of Forest site-I and site-II. (Values in parentheses are the relative percentage of the total).

Litter components	N	P	K	Na
	FOREST SITE-I			
	Return			
Leaf	73.89 (93.03)	4.58 (95.03)	15.10 (94.55)	2.56 (94.82)
Miscellaneous	5.54 (6.97)	0.24 (4.97)	0.87 (5.45)	0.14 (5.18)
Total	79.43	4.82	15.97	2.70
	Release			
	48.36	2.76	9.67	1.38
	FOREST SITE-II			
	Return			
Leaf	44.47 (89.16)	2.17 (87.85)	9.64 (92.16)	0.97 (95.09)
Miscellaneous	5.41 (10.84)	0.30 (12.15)	0.82 (7.84)	0.05 (4.91)
Total	49.88	2.47	10.46	1.02
	Release			
	31.90	1.50	6.62	0.30

Table 12. The return and release of nutrients (kg ha^{-1}) (N,P,K and Na) in forest site-I and site-II. (Values in parentheses are the relative percentage of the total).

reflect the pattern of nutrients cycling in the forest ecosystem. The turnover time for nutrients (N, P, K and Na) in the trees of forest site-I was in the order: P (16.10 years) > Na (5.72 years) > K (5.23 years) and the value of turnover time in the oak forest site-II was in the order: Na (7.79 years) > P (7.70 years) > K (7.66 years) > N (7.51 years). The higher value in site-II may be due to difference in the species composition and *Rhododendron arboreum* is one of the species present in this site which exhibited very slow rate of decomposition (Laishram and Yadava 1988). Estimates of turnover of nutrients in post oak-blackjack oak forest (Johnson and Risser 1974) and in northern hardwood forests (Whittaker *at al* 1979) were N 5.2-10.4 years, P 6.4-9.9 years and K 3.2-14.6 years. The mean turnover time for oak forests in Central Himalayas was: 18.8 years, Na, 17.7 years, N, 17.6 years, P, 13.5 years (Rawat and Singh 1988) and were higher than the present estimates. Thus, it indicates that rate of cycling is faster in the present oak forest in north eastern region owing to longer growing season and high rainfall.

Turnover of nutrients on the forest litters

The values of turnover rate for N, P, K and Na in the forest litter of forest site-I was 0.60 N, 0.60 P, 0.58 K and 0.62 Na and in forest site-II was 0.63 N, 0.63 P, 0.64 K and 0.66 Na. However, turnover time ranges for various nutrients between 1.59 (Na) and 1.69 (K) in site-I and 1.50 (Na) and 1.58 (N) in site-II. In the present study the turnover of rate of nutrients on forest litter is faster compared to other temperate forests and more or less similar to value reported by Rawat and Singh (1988) for Central Himalayan oak forest. The values for turnover time are comparatively lower than that of mixed oak forest in USA reported by Cromack and Monk (1975) and northern hardwood forest in USA reported by Gosz, Likens and Bormann (1973) but are slightly higher than the values reported by Pandey and Singh (1981) and Rawat and Singh (1988) for oak-conifers and oak forest in Central Himalayas.

Nutrient use efficiency

The values for nutrients use efficiency for N, P, K and Na was 86.5 N, 1310.5 P, 346.2 K and 1922.7 Na g dry matter/g nutrient in forest site-I and 85.7 N, 2780.4 P, 415.0 K and 5359.9 Na g dry matter/g nutrient in forest site-II respectively. In forest site-I the requirement of nitrogen was slightly low but higher for phosphorus, sodium and potassium in comparison to site-II. Thus, forest site-II exhibited higher nutrient use efficiency except for nitrogen and was represented both by semi evergreen and deciduous species whereas site-I was dominated by semi evergreen species. However, further studies are required to investigate the pattern of nutrient use efficiency in different types of forest community for the maintenance of soil fertility in the natural ecosystem.

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