Proc. Indian Acad. Sci. (Plant Sci.), Vol. 98, No. 3, June 1988, pp. 215–226.

Pattern of immobilization and release of nitrogen in decomposing leaf litter in Himalayan forests

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MS received 30 April 1987; revised 20 January 1988

Abstract. The nitrogen dynamics in decomposing leaf litter, incubated on different forest sites were observed for a two year period. There existed an inverse relationship between the per cent dry matter remaining and its nitrogen concentration ($r = -0.713$ to -0.966). Litter, placed at sal, pine-mixed broadleaf and mixed oak forest sites showed larger slopes (showing greater weight loss per unit of nitrogen immobilization) compared to pine and mixed oak-pine forest sites. The magnitude of immobilization of nitrogen was different among species at different forest sites. The decomposition constant (k) for organic matter ranged from -1.29 to -4.61 and for N release -1.05 to 3.91. Analysis of variance indicated significant differences in N concentration due to days, species and species × days interaction ($P<0.01$).

Keywords. Decomposition; immobilization; Himalayan forests; leaf litter; nitrogen concentration; decomposition constant.

1. Introduction

Decomposition processes play an important role in soil fertility, in terms of nutrient cycling and maintenance of organic matter level. The mineralization of elements through the decay of organic matter represents a large, available source of nutrients for plants (Clarke 1977; Jorgensen *et al* 1980). Slow decay rate can produce nutrient limitations to primary producers by accumulating large nutrient stock in soil surface. Nitrogen and lignin are the major substrate quality components controlling the rate of decomposition (Staaf and Berg 1982; Berg and Wessen 1984; Mellilo *et al* 1982). Plant nutrients are released from litter either by physical leaching or by breakdown of structural organic components by saprotrophic organisms. Often the later process is quantitatively more important, and the rate at which elements are released could thus be expected to be governed largely by the decomposition rate. The present study describes (i) the changes in the concentration and pattern of release of nitrogen and (ii) influence of initial substrate quality on immobilization and release of decomposing litter from a number of species from 5 forest ecosystems of Kumaun Himalaya.

2. Study sites

2.1 *Location*

The experimental sites are located in the north western part of the central Himalaya (29° 7′ to 29° 26′ N lat. and 79° 15′ to 79° 38′ E long.) and range from 330–2150 m in altitude.

2.2 *Climate*

Based on the climatic variations in central Himalaya, the year is divisible into 3 seasons: rainy (July–October), winter (November–February) and summer (March–June).

The sal forest site is situated at 330 m elevation and represents the warmest habitat whereas mixed oak forest site (2150 m) represents the coldest. Mean daily temperature ranges between 12–32°C (sal) and 4·5–22°C (mixed oak). The temperature of remaining 3 sites fall between these two. Mean annual rainfall is 2076, 2005, 2185, 1313 and 2488 mm respectively, at Sal, pine-mixed broadleaf, pine, mixed oak-pine and mixed oak forest sites, 76–88% of which occurs in the rainy season.

2.3 *Geology*

Sal and pine-mixed broadleaf forest sites are situated on Siwalik rocks. The rocks mainly comprise thickly-bedded hard, compact sandstone associated with purple, red and green slates. The pine forest site, being situated in the northern proximity of main boundary thrust, has purple, and green slates interbedded with yellowish weathering dolomite (middle Krol) or greyish green calcareous slates with a thin layer of marl (lower Krol). At the mixed oak-pine forest site the exposed rocks are grey to greyish green garnetiferous mica schist and granitic gneisses. The rocks exposed at the mixed oak forest site are of Blaini formation and comprise pink dolomitic limestone with rounded to well-rounded clasts of quartzite, purple slate and silt stone (A K Sharma, unpublished results).

2.4 *Site characterization*

Soil on the sal forest site is deep and alluvial, while that at higher altitudes is shallow and residual. The coarse particles in soil in 0–30 cm soil cores were negligible at sal forest sites compared to remaining sites (11–28%). Soil texture was determined by soil hydrometer (Buoyoucos 1951), organic carbon by Walkley and Black's (1934) rapid titration method and total nitrogen by Kjeldahl method as described by Piper (1944). Sand predominates in the soil (61–82%) on all sites, while the silt and clay percentages range between 12–26 and 6–16 respectively. Across the sites, organic carbon ranged between 1·10–4·20% and total nitrogen between 0·15–0·40% (table 1).

3. Materials and methods

3.1 *Leaf litter decomposition*

Mature nearly senesced but attached leaves were collected from the middle canopy of trees of selected species in June–July 1981 and air-dried in shade. Leaf fall in the present forests occurs throughout the year although the peak fall occurs during the summer season (Pandey and Singh 1982; Mehra 1984).

The litter bag technique was used for quantifying the rate of decomposition. Nylon netting litter bags (1 mm mesh) of 10 × 10 cm size, containing 5 g air-dried leaf litter were placed on the forest floor of the forest sites (table 2). Although, various methods

Table 1. Some physical and chemical properties of soils in the study sites.

	Forest				
	Sal	Pine-mixed broadleaf	Pine	Mixed oak-pine	Mixed oak
Colour	Dark brown	Dark brown	Dark brown	Dark yellowish brown	Dark brown
Texture (%)					
Sand	80	82	66	61	62
Silt	14	12	24	26	22
Clay	6	8	10	13	16
Organic carbon (%)	1·08	3·54		3·54	4·20
Total nitrogen (%)	0·15	0·30	0·26	0·33	0·46
C/N ratio	7·13	11·60	14·27	10·40	9·21

Table 2. Date of litter bag placing and number of litter bag placed for species at different forest sites.

Forest type	Leaf litter species	Numbers of bags	Date placed
Sal	*Shorea robusta*	120	7 July 1981
	Mallotus philippensis	80	
	Quercus leucotrichophora	120	
Pine-mixed broadleaf	*Lyonia ovalifolia*	120	7 July 1981
	Quercus glauca	80	
	Rhododendron arboreum	80	
	Quercus leucotrichophora	120	
Pine	*Pinus roxburghii*	120	7 August 1981
	Quercus leucotrichophora	120	
Mixed oak-pine	*Quercus leucotrichophora*	120	7 August 1981
	Myrica esculenta	80	
Mixed oak	*Quercus lanuginosa*	120	8 July 1981
	Quercus floribunda	80	
	Quercus leucotrichophora	120	

available for investigating decomposition rates have several drawbacks. The use of litter bags provides a standardised basis for comparisons among species, sites and experimental manipulations (Singh and Gupta 1977; Wieder and Lang 1982).

Litter bags of *Quercus leucotrichophora* were placed on the forest floor of each site. The leaf litter of *Q. leucotrichophora*, collected from its native site, was used as a standard material for investigating the effect of habitat on decomposition.

On the sal forest site, steel wire netting bags with the same mesh size and painted with synthetic enamel to avoid rusting, were used because termites damage nylon bags. Five replicates, 5 g air-dried weight each, from stock litter samples were dried at 70°C to determine a correction factor for estimating the initial oven dry weight of litter in bags.

Five litter bags were randomly recovered (for those species where 120 bags placed) at one month interval over a year. Two litter bags were used to determine the microbial and microfaunal populations of the decomposing litter in a related study (Pande 1984; Sharma *et al* 1984). For the remaining species only 3 bags were recovered at one-month intervals over a year. In a number of species the decomposition was not completed over a year. In these cases the bags were recovered beyond one year until the litter had disappeared or in one species (*Pinus roxburghii*), till the second year was complete. The litter bags immediately after recovery were placed in individual polyethylene bags and transported to the laboratory. In the laboratory the residual litter was separated from the bags and was carefully cleaned to remove the attached soil particles and weighed. This material was then oven-dried at 70°C to constant weight to calculate the weight loss and moisture content.

3.2 *Chemical analysis*

Total (Kjeldahl) nitrogen (Piper 1944) was determined in litter samples collected at 2-month intervals over the first year. Two further N analysis were carried out after 16 and 19½ months for species with significant residual masses of litter material. By combining these results with the data on weight loss the N mobilisation after different incubation periods were calculated. Annual decomposition coefficients (k) for nitrogen were calculated [$Xt/Xo = e^{-kt}$; where Xt = mass at time t, and Xo = initial mass and k = the annual exponential (base e) decay coefficient] following Olson (1963) after the last chemical analysis for each species and for organic matter after 100% decomposition was achieved (i.e. 99% of the initial weight had disappeared).

4. **Results**

4.1 *Changes in N concentration*

4.1a *Sal forest*: There was a continuous increase in N concentration of the residual litter throughout the decomposition period in all species, although the magnitude of the increase differed among species (table 3). The increase was greatest in *M. philippensis* and was followed by *S. robusta* and *Q. leucotrichophora*. At the end of the first year N concentration was 2·34 times that of the initial value for *S. robusta*, 3·42 times for *M. philippensis* and 1·82 times for *Q. leucotrichophora*.

4.1b *Pine-mixed broadleaf forest*: In the initial period of decomposition the increase occurred in *Q. glauca*, as after 62 days, N concentration reached 1·87% from the initial 0·94%. For the same period N concentration was 1·05% (initial 0·80%) for *L. ovalifolia*, 1·12% (initial 0·70%) for *R. arboreum* and 1·23% (initial 1·15%) for *Q. leucotrichophora*. After 487 days the N increase in *R. arboreum* was 2·40 times and in *Q. leucotrichophora* 2·10 times that of the initial concentration. Between 487 and 578 days, there was no increase in N concentration in the residual material of *R. arboreum*. Between these periods the decomposition of *Q. leucotrichophora* was complete.

4.1c *Pine forests*: The increase in N concentration was slightly greater in *P. roxburghii* (1·94 times) compared to *Q. leucotrichophora* (1·45 times of the initial) in the first year. The increase in N concentration at the end of 578 days was

Table 3. Changes in dry weight and N content of the leaf litter from several tree species, placed on different forest sites for different periods of decomposition.

Period after placement of bags (days) (1)	Weight of litter remaining (%) (2)	Weight of N (g) (3)	Weight of N (%) (4)	Weight of N (mg) (5)	Observed weight of N as per cent of initial (6)	Change in N content (%) (7)
			Sal forest			
S. robusta						
Initial	100	4·58	0·99	45	—	—
62	73·76	3·38	1·36	46	102	2
123	54·56	2·50	1·40	35	78	−22
184	47·21	2·16	1·45	31	69	−31
243	36·76	1·68	2·00	34	76	−24
304	15·42	0·71	2·22	16	36	−64
365	3·68	0·17	2·32	4	8	−92
	Total decomposition occurred in 396 days					
M. philippensis						
Initial	100	4·68	0·52	24	—	0
62	56·05	2·62	0·85	22	92	−8
123	38·42	1·80	1·20	22	92	−8
184	20·67	0·91	1·22	12	50	−50
143	10·51	0·49	1·64	8	33	−67
304	3·77	0·18	1·78	3	13	−87
	Total decomposition occurred in 365 days					
Q. leucotrichophora						
Initial	100	4·55	1·15	52	—	0
62	55·19	2·51	1·23	31	60	−40
123	38·49	1·75	1·40	25	48	−52
184	29·80	1·36	1·49	20	38	−62
243	16·38	0·75	1·62	12	23	−77
304	5·47	0·25	1·75	4	8	−92
365	1·26	0·06	2·09	1	2	−98
	Total decomposition occurred in 396 days					
L. ovalifolia						
Initial	100	4·68	0·80	37	—	0
62	45·52	2·13	1·05	22	59	−41
123	38·33	1·79	1·13	20	54	−46
184	31·10	1·46	1·17	17	46	−54
243	19·42	0·91	1·25	11	30	−70
304	14·02	0·66	1·72	11	30	−70
365	3·71	0·17	1·89	3	8	−92
	Total decomposition occurred in 396 days					
Q. glauca						
Initial	100	4·65	0·94	44	—	—
62	52·92	2·46	1·87	46	105	5
123	30·62	1·42	1·94	28	64	−36
184	24·41	1·14	2·12	24	55	−45
243	20·14	0·94	2·14	20	45	−55
304	10·91	0·51	2·24	11	25	−75
	Total decomposition occurred in 365 days					
R. arboreum						
Initial	100	4·85	0·70	34	—	—
62	75·74	3·67	1·12	41	121	21
123	63·57	3·08	1·20	37	109	9

Table 3. (*Contd.*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
184	59·86	2·90	1·24	36	106	6
243	55·22	2·68	1·26	34	100	0
304	40·09	1·94	1·30	25	74	−26
365	27·59	1·34	1·52	20	59	−41
487	9·74	0·47	1·68	8	24	76
578	4·54	0·22	1·68	4	12	−88
	Total decomposition occurred in 608 days					
Q. leucotrichophora						
Initial	100	4·55	1·15	52	—	0
62	68·92	3·14	1·23	39	75	−25
123	60·20	2·74	1·34	37	71	−29
184	51·30	2·33	1·53	36	69	−31
243	44·26	2·01	1·74	35	67	−33
304	27·74	1·26	1·78	22	42	−58
365	12·95	0·59	1·95	12	23	−77
487	2·55	0·12	2·42	3	6	−94
	Total decomposition occurred in 520 days					
			Pine forest			
P. roxburghii						
Initial	100	4·52	0·67	30	—	0
62	80·48	3·64	0·79	29	97	−3
123	79·00	3·57	0·97	35	117	17
184	73·31	3·31	1·01	33	110	10
243	64·96	2·94	1·15	34	113	13
304	55·88	2·53	1·24	31	103	3
365	48·73	2·20	1·30	29	97	−3
487	33·71	1·52	1·35	21	70	−30
578	28·23	1·28	1·39	18	60	−40
730	7·56	0·34	1·39	5	17	−83
Q. leucotrichophora						
Initial	100	4·55	1·15	52	—	0
62	75·52	3·44	1·14	39	75	−25
123	73·58	3·35	1·20	40	77	−23
184	71·96	3·27	1·26	41	79	−21
243	51·53	2·34	1·35	32	62	−38
304	41·26	1·88	1·42	27	52	−48
365	26·07	1·19	1·67	20	38	−62
487	13·36	0·61	1·82	11	21	−79
578	9·22	0·42	2·12	9	17	−83
	Total decomposition occurred in 669 days					
			Mixed oak-pine forest			
Q. leucotrichophora						
Initial	100	4·55	1·15	52	—	0
62	70·13	3·19	1·16	37	71	−29
123	64·40	2·93	1·16	34	65	−35
184	56·64	2·58	1·20	31	60	−40
243	45·85	2·09	1·31	27	52	−48
304	37·22	1·69	1·84	31	60	−40
365	23·62	1·07	1·97	21	40	−60
487	8·56	0·39	2·12	0	15	−85
578	3·27	0·15	2·27	3	6	−94
	Total decomposition occurred in 609 days					

Table 3. (*Contd.*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
M. esculenta						
Initial	100	4·72	0·58	27	—	0
62	87·70	4·14	0·68	28	104	4
123	87·68	4·14	0·81	34	126	26
184	66·69	3·15	0·85	28	104	4
243	61·97	2·92	0·97	28	104	4
304	43·24	2·04	1·05	21	78	−22
365	26·84	1·27	1·12	14	52	−48
487	14·08	0·66	1·20	8	30	−70
578	7·96	0·38	1·25	5	19	−81
Total decomposition occurred in 639 days						
Mixed oak forest						
Q. lanuginosa						
Initial	100	4·64	1·32	61	—	0
62	75·78	3·52	1·76	62	102	2
123	67·31	3·12	1·45	45	74	−26
184	62·52	2·90	1·41	41	67	−32
243	51·12	2·37	1·44	34	56	−44
304	41·42	1·92	1·84	35	57	−43
365	32·07	1·49	2·66	40	66	−34
487	12·09	0·56	2·87	16	26	−74
578	6·47	0·30	3·12	9	15	−85
Total decomposition occurred in 669 days						
Quercus floribunda						
Initial	100	4·67	0·97	45	—	0
62	76·35	3·57	1·12	40	89	−11
123	70·85	3·1	1·02	34	76	−24
184	65·33	3·05	1·32	40	89	−11
243	50·77	2·37	1·87	44	98	−2
304	43·23	2·02	2·71	55	122	22
365	35·92	1·68	3·05	51	113	13
487	13·12	0·61	3·10	19	42	−58
578	5·48	0·26	3·15	8	18	−82
Total decomposition occurred in 669 days						
Q. leucotrichophora						
Initial	100	4·55	1·15	52	—	0
62	63·68	2·90	1·18	34	65	−35
123	51·82	2·36	1·32	31	60	−40
184	50·00	2·28	1·12	26	50	−50
243	41·36	1·88	1·33	25	48	−52
304	24·86	1·13	1·68	19	37	−63
365	12·87	0·59	2·55	15	29	−71
487	1·27	0·06	2·68	2	4	−96
Total decomposition occurred in 548 days						

P. roxburghii (2·09 times greater than the initial) and *Q. leucotrichophora* (1·84 times from the initial) (table 3).

4.1d *Mixed oak-pine forest*: Increase in N concentration was greater in *M. esculenta* than in *Q. leucotrichophora.* After 365 days the increase was 1·71 and

1·93 times and after 578 days it was 1·97 and 2·16 times of the initial value for *Q. leucotrichophora* and *M. esculenta* respectively (table 3).

4.1e *Mixed oak forest*: The litter of oak species showed an increase in N concentration in initial periods of decomposition followed by a decrease in the winter season. After the first winter all species exhibited an increase in N concentration (table 3). The increase was more than 3 times in *Q. floribunda* at the end of the first year. For the same period increase was 2·02 and 2·22 times of the initial in *Q. lanuginosa* and *Q. leucotrichophora* respectively. In *Q. leucotrichophora* N concentration reached 2·68% (initial 1·15%) in 487 days of litter incubation. After 578 days, N concentration was 3·12% compared to the initial 1·32% for *Q. lanuginosa* and 3·15% compared to the initial 0·97% for *Q. floribunda.*

Thus, varying degrees of N immobilization were observed for the species at different forest sites and the magnitude of immobilization was different among species. Analysis of variance indicated significant differences in N concentration due to days and species ($P<0{\cdot}01$) across sites. A significant interaction ($P<0{\cdot}01$) between species and days indicates that the behaviour of litter species in this regard varied across dates.

4.2 *Nitrogen release during decomposition*

4.2a *Sal forest*: Initial release was much faster in *Q. leucotrichophora* compared to *M. philippensis. S. robusta* did not release N in initial periods and an absolute increase of 0·21 mg N mass per litter bag occurred after 62 days of litter incubation. In the later periods of the cycle, *S. robusta* showed faster release compared to *M. philippensis* and *Q. leucotrichophora.* However, in the total period faster N release occurred in *Q. leucotrichophora* ($k=3{\cdot}91$) and *S. robusta* ($k=2{\cdot}52$) followed by *M. philippensis* ($k=2{\cdot}49$) (table 4).

4.2b *Pine-mixed broadleaf forest*: N release in initial periods was faster in *L. ovalifolia* and *Q. leucotrichophora*, whereas an increase in absolute mass of N was observed in *Q. glauca* and *R. arboreum.* About 39% of total N was released from *Q. glauca* at the end of 123 days, whereas for the same period in other 3 species the release of N was 4–12% only. However, for the total decomposition cycle N release was faster in *L. ovalifolia* ($k=2{\cdot}53$) followed by *Q. leucotrichophora* ($k=2{\cdot}12$), *Q. glauca* ($k=1{\cdot}69$) and *R. arboreum* ($k=1{\cdot}34$) (table 4).

4·2c *Pine forest*: Initial release was only 3% followed by an increase of 1·32 mg N mass per litter bag, in *P. roxburghii*, whereas initial release was 25% and a net increase of 0·22 mg N mass per litter bag in *Q. leucotrichophora* after 123 days (table 3). In the total decomposition cycle N release was faster in *Q. leucotrichophora* compared to *P. roxburghii* as annual decomposition constants were 1·12 and 0·89 respectively, for the two species (table 4).

4·2d *Mixed oak-pine forest*: *Q. leucotrichophora* exhibited 29% release of total N after 62 days of litter incubation, whereas *M. esculenta* showed 4 and 26% increase in absolute mass after 62 and 123 days respectively (table 3). However, a net increase of 0·88 mg was observed in the release phase of *Q. leucotrichophora* after 304 days. The

Table 4. Annual decomposition constant (k) for nitrogen and organic matter for decomposing leaves of several species from different forest sites.

		k	
Forest site	Species	Organic matter	N
Sal	*S. robusta*	4·25	2·52
	M. philippensis	4·61	2·49
	W. leucotrichophora	4·25	3·91
Pine-mixed broadleaf	*L. ovalifolia*	4·25	2·53
	Q. glauca	4·61	1·69
	R. arboreum	2·77	1·34
	Q. leucotrichophora	3·23	2·12
Pine	*P. roxburghii*	1·29	0·89
	Q. leucotrichophora	2·52	1·12
Mixed oak-pine	*Q. leucotrichophora*	2·76	1·78
	M. esculenta	2·63	1·05
Mixed oak	*Q. lanuginosa*	2·52	1·20
	Q. floribunda	2·52	1·08
	Q. leucotrichophora	3·07	2·42

annual decomposition constant was 1·78 for *Q. leucotrichophora* and 1·05 for *M. esculenta* (table 4).

4.2e *Mixed oak forest*: Decrease in N weight was observed in *Q. floribunda* and *Q. leucotrichophora* in initial periods, whereas *Q. lanuginosa* showed an increase in total weight of N of 0·21 mg. A net increase of 1·29, 0·85 and 2·36 mg N per litter bag was observed in *Q. floribunda* after 184, 243 and 304 days of litter incubation, whereas the other two species showed a continuous release. The annual decomposition constant was 1·20 for *Q. lanuginosa*, 1·08 for *Q. floribunda* and 2·42 for *Q. leucotrichophora* (table 4).

5. Discussion

The increase in N concentration in decomposing litter shown in this study is a generally occurring phenomenon brought about by microbial immobilization of N while C is mineralized (Bocock 1963; Gosz *et al* 1973; Berg and Staaf 1981; Anderson *et al* 1983; Fahey 1983; Vogt *et al* 1983). A decline in N concentration in winter was observed at the mixed oak forest site. This site experiences frequent snowfall in winter and it is probable that the decline represents a flushing by snow melt which increases the biological activity and decay rate. Bogatyrev *et al* (1983) noted that freezing and thawing slightly increased the leaching rate for birch litter. McBrayer and Cromack (1980) also reported a decrease in N concentration in winter periods under snow cover in decomposing oak leaf litter.

Significant negative relationships were found between N concentration in residual material and the per cent weight remaining for all species. The regression parameters for these relationships are given in table 5. Aber and Melillo (1980) and Melillo *et al*

(1982) have emphasized the significance of these relationship in the framework of immobilization and mineralization of N during decomposition. The weight loss in enclosed litter and increased N concentration in the residual material reflect carbon metabolization and N immobilization respectively, by micro-organisms. Aber and Melillo (1980) have generalized that this relationship is inversely linear in case where (i) physical removal of material from bags is minimized, (ii) nitrogen is sufficiently low in concentration in the litter material to be limiting to microbes and (iii) a continuous external source of N is available.

Further, Aber and Melillo (1980) stated that on these sites, where litter feeding activities are high, the physical removal by the animals results in increased variability in the measured N concentrations. They found poorer correlation and increase in the slope on such sites. This could result from the selective feeding by the macrofauna on more palatable high nitrogen material being constantly produced by the microbial growth and activity. Litter, placed on sal, pine-mixed broadleaf and mixed oak forest sites, in the present study exhibited larger slopes compared to pine and mixed oak-pine forest sites. This has come due to greater weight loss of litter in the former species per unit of N immobilization.

On these 3 forest sites micro-arthropod population on the forest floor was greater than the pine and mixed oak-pine forest sites (Sharma *et al* 1984). Invasion of microbial population on the litter bags on these forest sites was also greater compared to species of other forest sites (Pande 1984). Also on these 3 forest sites average annual rainfall was also high, 80–88% of which occurs in the rainy season.

According to Waksman and Gerretsen (1931), for every unit of carbon oxidised by micro-organisms a certain amount of N must be assimilated whether it is present in the form of proteins or protein derivatives of inorganic salts. The sources of N taken up by the decomposing litter are not well established. Bocock (1963) considered atmospheric precipitation, insect frass and plant material falling from the canopy as N sources. Staaf and Berg (1977), however, reported that the amount of N in

Table 5. Regression parameters relating per cent weight remaining (Y) and nitrogen concentration (X %) in residual material.

Forest site	Species	Intercept	Slope	%	'*t*' value	SE of slope	d.f
Sal	*S. robusta*	153·01	−63·01	0·916	7·37	8·54	5
	M. philippensis	125·27	−72·43	0·914	6·56	11·04	4
	Q. leucotrichophora	178·13	−93·23	0·770	4·09	22·77	5
Pine-mixed broadleaf	*L. ovalifolia*	125·68	−69·66	0·713	3·53	19·76	5
	Q. glauca	165·40	−66·97	0·959	9·70	6·89	4
	R. arboreum	178·16	−99·75	0·958	12·55	7·92	7
	Q. leucotrichophora	157·83	−67·71	0·898	7·85	8·62	6
Pine	*P. roxburghii*	159·67	−88·43	0·923	9·14	9·66	7
	Q. leucotrichophora	175·63	−85·16	0·861	6·61	12·89	7
Mixed oak-pine	*Q. leucotrichophora*	138·79	−59·24	0·822	5·69	10·41	7
	M. esculenta	187·48	−140·06	0·966	14·03	9·97	7
Mixed oak	*Q. lanuginosa*	124·10	−37·21	0·769	4·83	7·70	7
	Q. floribunda	110·29	−28·82	0·858	6·51	4·42	7
	Q. leucotrichophora	103·16	−36·81	0·593	2·97	12·72	6

All equations are significant at $P<0·01$.

precipitation could not account for the N accumulated in the Scots-pine needle litter. They suggested that N was taken up by the decomposing litter from older litter on the floor with a higher N content. Increased N mass in the initial periods in most of the species suggests that N was strongly immobilized in microbial tissues (Gosz *et al* 1973; Jorgensen *et al* 1980). Ausmus *et al* (1976) have also found absolute increase and stated that it occurred probably due to progressive reduction in the amount of organic carbon present.

Initial nutrient compositions especially lignin and N exert greater influence on N accumulation (Staaf and Berg 1982; Berg and Wessen 1984). In the present experimental species N accumulation took place for longer periods in *P. roxburghii* and *M. esculenta*. These two species have lowest initial N concentration and highest lignin content compared to other species (Upadhyay and Singh 1985). The lignin fraction have relatively low availability to plants and causes low turnover for these species. All other species except these two have $<17\%$ lignin. Upadhyay and Singh (1985) have also shown that in species having $<17\%$ lignin little or no accumulation of N occurred. The pattern of nitrogen release in *Q. leucotrichophora* at all sites and of *L. ovalifolia* followed the total weight loss pattern during the initial periods of decomposition, suggesting leaching of the mobile N pools i.e. labile fractions of litter. In *M. philippensis* also the release of N was only slightly lower compared to the loss of organic matter. Staaf and Berg (1982) argued that some decomposition of lipophilic substances in the cuticle and membranes may take place even before the litter is effectively wetted. The release phase was dominant in *Q. leucotrichophora*, *L. ovalifolia* and *M. philippensis*, but a temporary net import of N was observed in *Q. leucotrichophora* (at pine and mixed oak-pine forest sites). Similar observations in decomposing pine needle litter were reported by Berg and Staaf (1981). The beginning of a decrease in weight of N after an accumulation suggests the occurrence of mineralization.

Acknowledgement

The author gratefully acknowledges financial support from the Department of Science and Technology, New Delhi.

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