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LEAF LITTER DECOMPOSITION AND CALCIUM RELEASE IN FORESTS OF CENTRAL HIMALAYA

V. P. Upadhyay

Department of Botany, Kumaun University, Nainital (U. P.)

ABSTRACT : The losses of weight and calcium from decomposing leaves were studied for 2 years period in ten species of five different Central Himalayan forest ecosystems. One standard leaf species was kept on all sites to observe the effect of habitat on weight loss and calcium immobilization and release. The loss in weight as well as in calcium was higher for sal forest site species and was lower for pine forest species. Immobilization of calcium was observed at pine and mixed oak-pine forest sites for initial period only. In most of the species release of Ca was proportional to weight loss. All the species at all sites experienced total loss [100%] of weight and calcium between 365 to 669 days, where as *Pinus roxburghii* exhibited only 92% weight loss and 85% calcium loss in two years of decomposition.

Key words : Leaf litter, weight loss, immobilization, Calcium, Central Himalaya.

INTRODUCTION

The integrity of an ecosystem is maintained by the transfer of matter and energy between producers, consumers and decomposers. A major part of the annual gain of energy and matter by plants is shed as litter which enters into the decomposition subsystem as dead organic matter or detritus. The rate and pathways of litter decomposition are determined by the qualitative and quantitative composition of the decomposer community, their physical environment and the substrate quality (Swift *et al.* 1979). The accepted pathway of decomposition of plant debris in the soil has been summarised as follows : (i) development of phylloplane microflora, (ii) colonization of saprophagic micro-organisms, (iii) comminution and ingestion by invertebrates resulting into an increase in the surface area but little chamical change, (iv) microbial colonization, utilization of faeces and comminuted litter resulting into chemical degradation of tissues and production of complex phenolic polymers (humic acid), and (v) formation of stable organo-mineral complexes (Wood 1976). Thus, the decomposer subsystem performs two major function viz; the mineralization of essential elements and formation of soil organic marter. The ways in which these two processes are accomplished determine to a large extent the structural and functional features of ecosystems. The rate of movement of essential nutrients through decomposition in an important regulator of primary production. The present study deals with the changes in weight and calcium and pattern of losses during the time course of decomposition in the forest leaf litters in Central Himalaya.

STUDY SITES

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 vary from 330 m to 2150 m in altitude.

The climate of the sal forest site can be referred to as monsoon subtropical. The annual rainfall is 2076 mm, 88% of which occurs during the rainy season. The monthly mean daily temperature ranges from 13.1°C to 32°C. At the pine–mixed broad leaf site climate is intermediate between subtropical monsoon to temperate monsoon. Annual rainfall is 2005 mm, 80% of which occurs during the rainy season. Monthly mean daily temerature ranges from 7.9°C to 23.9°C. The Pine forest site receives 2185 mm annual rainfall, 80% of which occurs during the rainy season. Monthly mean daily temperature ranges from 7.8°C to 21.1°C.

The mixed oak-pine forest site receives 1313 mm annual rainfall, of which 76% occurs during the rainy season. Monthly mean daily temperature varies from 7.8°C to 22.1°C. Snow fall occurs in winters. The site experiences a monsoon temperate climate. The mixed oak forest site receives 2488 mm rainfall annually, 86% of which occurs during the rainy season. Monthly mean daily temperate varies from 6.0°C to 20.5°C. The climate is monsoon temperate. Snow falls frequently during winter season, however, no quantitative data exist.

Sal and pine mixed broad- leaf 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 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 grouped into Blaini formation and comprise pink dolomite limestone with rounded to well-rounded clasts of quartzite, purple slate and silt stone.

Soil on the sal forest site is deep and alluvial, while that at higher altitudes is shallow and residual. Soil texture was determined by soil hydrometer (Bouyaucos 1951), organic carbon by walkley and Black's rapid titration method and total nitrogen by macrokjeldahl 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 to 4.20% and total nitrogen between 0.15 to 0.40%.

Vegetation : The study sites are markedly different from each other with respect to botanical composition. The phytosociological analysis for trees was accomplished by using appropriate number of quadrats of requisite size, determined after Kershaw (1973) and Misra (1968). Trees (with >31.5 cm cbh) and saplings (with 10.5–31.4 cm cbh) were measured and recorded on all sites. Analytical compostion of tree and sapling layers on different sites are summarized here briefly. The Importance Value Index (IVI) for the tree species was determined as the sum of relative frequency, relative density and relative dominance (Curtis, 1959). Relative frequency, relative density and relative dominance were determined following Philips (1959). At the sal forest site, total basal area of *S. robusta* was 51.21 m^2 ha^{-1}, and of *M. philippinensis*, 3.36 m^2 ha^{-1}. Density and IVI of *S. robusta* in the tree layer was also greatest. Saplings of *S. robusta* were absent, and of *M. philippinensis* had a maiximum density (44 individuals ha^{-1}), basal area (0.12 m^2 ha^{-1}) and IVI (216) followed by *Cassia fistula*. At the pine-mixed broadleaf forest site, density, basal area and IVI was higher for *P. roxburghii* (63 individuals ha^{-1}, 12.74 m^2 ha^{-1} and 85, respectively) and *Q. leucotrichophora* (30 individuals ha^{-1}, 3.52 m^2 ha^{-1} and 36, respectively) followed by *Syzygium cumini*, *Machilus duthiei*, *Myrica esculenta* and *Lyonia ovalifolia*. The dominants of the sapling layar were *Symplocos ramosissima* (IVI = 74) and *L. ovalifolia* (IVI = 41).

At the pine forest site, *P. roxburghii* accounted for as much as 82% of the stand IVI. In the sapling layer, this species was again dominant (IVI = 169) followed by *M. esculenta* (IVI = 75) and *Pyrus pashia* (IVI = 56). *Q. leucotrichophora* at the mixed oak-pine forest site showed the greatest IVI (135) followed by *P. roxburghii* (55) and *M. esculenta* (55). The sapling population consisted of 225 individuals ha^{-1}, of which about 1/3rd belonged to *Q. leucotrichophora* and about 1/5th to *M. esculenta*, *P. roxburghii* and *Acacia nilotica*. At the mixed oak forest site, *Quercus lanuginosa* was the dominant species in the tree layer (IVI = 179) as well as in the sapling layer (IVI = 234). followed by *Quercus floribunda* (tree layer, IVI = 80 : sapling layer, IVI = 49).

MATERIAL AND METHODS

Decomposition of leaf litter of 10 tree species was studied following litter bag technique, on five forest sites, along an altitudinal gradient of 300–2150 m. Leaf litter of one of the species viz.; *Quercus leucotrichophora* A. Camus was placed at all sites to study the impact of site characteristics on decomposition. A total of 120 litter bags were placed for dominant species and 80 bags for sub-dominant species. Nylon litter bags (1 mm mesh and 10 x 10 cm. size) contained 5 g airdried leaf litter samples. The date of placement of leaf litter bags on different forest sites are given in Table 1. At the sal forest site, because of preponderance of termites, steel wire netting mesh bags were used, which were painted with synthetic enamel to avoid rusting. Five litter bag samples of each species from each of the forest environment were collected every month for determination of oven dry weight and calcium content in residual material. The Ca content in the fresh ovendried litter as well as in the residual litter was determined by atomic absorption spectrophotometry (Issac and Kerber 1974). The analysis for Ca was conducted after each 60th day during one annual cycle. Two further analyses were made after the annual cycle on 488 and 578 days for the material still remaining in the bags.

RESULTS AND DISCUSSION

Weight loss : At the sal forest site *S. robusta* and *Q. leucotrichophora* completed decomposition in 396 days and *Mallotus philippinensis* in 365 days. On the pine-mixed broadleaf forest site, *L. ovalifolia* and *Q. glauca* decomposed in 396 and 365 days, respectively, and on the same site *R. arboreum* and *Q. leucotrichophora* decomposed, respectively in 608 and 520 days. At the pine forest site, 92% decomposition occurred in *P. roxburghii* in two years, while *Q. leucotrichophora* completely decomposed in 22 months. At the mixed oak-pine forest site decomposition was complete in 609 days and 639 days, respectively, for *Q. leucotrichophora* and *M. esculenta*. At the mixed oak forest site *Q. leucotrichophora* decomposed in 548 days and both *Q. floribunda* and *Q. lanuginosa* in 669 days.

The mean relative decomposition rates were generally higher in rainy and summer seasons and lower in the winter season. Moderate temperatures and abundant moisture in the rainy season, and higher temperatures of the summer season are congenial for decomposition.

The weight loss of *S. robusta* was not significantly different from that of *M. philippinensis* and *Q. leucotrichophora* (on sal oldgrowth forest site) in rainy season, but it was significantly different in winter and summer seasons from *M. philippinensis* and in winter season from *Q. leucotrichophora* ($p<0.01$). The weight loss of *M. philippinensis* was different from that of *Q. leucotrichophora* in rainy season ($p<0.05$) (Table 1). At the pine-mixed broadleaf forest site weight loss of *L. ovalifolia* differed significantly from *R. arboreum* in rainy ($p<0.05$), summer and winter seasons ($p<0.01$) with *Q. leucotrichophora* in winter and summer seasons ($p<0.01$) with *Q. glauca* in summer season ($p<0.05$). The weight loss of *Q. glauca* was different in all seasons from that of *R. arboreum* and *Q. leucotrichophora* ($p<0.01$). *R. arboreum* differed significantly from *Q. leucotrichophora* in summer season only ($p<0.01$). At pine forest site the weight loss of *P. roxburghii* differed significantly with *Q. leucotrichophora* in all seasons ($p<0.05$). At the mixed oak-pine forest site *Q. leucotrichophora* differed significantly from *M. esculenta* also in all seasons ($p<0.01$). At the mixed oak forest site the weight loss of *Q. lanuginosa* did not differ from that of *Q. floribunda*, but it was significantly different from that of *Q. leucotrichophora* in winter season ($p<0.01$). *Q. floribunda* differed significantly from *Q. leucotrichophora* in rainy ($p<0.5$) and summer seasons ($p<0.01$). This analysis indicates a strong interaction between species and seasons. In addition, the weight loss in each pair or species was different in one season or other. Thus, the rate and pattern of decomposition is markedly affected by climatic conditions.

Calcium Release: The pattern of Ca release in *M. philippinensis* and *Q. leucotrichophora* at the sal forest site closely paralleled the weight loss pattern throughout the decomposition period, whereas the Ca release was proportionally higher than that of weight loss in *S. robusta* (Table 1). Initial release was 46,44 and 41%, respectively, in *M. philippinensis*, *S. robusta* and *Q. leucotrichophora*. In the later periods of decomposition, *M.*

Table 1 : Changes in Calcium content of the leaf litter species, placed on different forest sites for different periods of decomposition.

Period after placement of bags (days)	Weight of litter remaining %	g	Observed weight of Ca content %	mg	Observed weight of Ca as per cent of initial	% change in Ca content
			SAL FOREST			
S. robusta :						
Initial	100	4.58	1.63	74.7	—	0
62	73.76	3.38	1.46	49.3	66.0	-44.0
123	54.56	2.50	1.36	34.0	45.5	-54.5
184	47.21	2.16	1.34	28.9	38.7	-61.3
243	36.76	1.68	1.27	21.3	28.5	-71.5
304	15.42	0.71	1.12	8.0	10.7	-89.3
365	3.68	0.17	1.09	1.9	2.5	-97.5
M. philippinensis :						
Initial	100	4.68	2.13	99.7	—	0
62	56.05	2.62	2.05	53.7	53 9	-46.1
123	38.42	1.80	1.82	32.8	32.9	-67.1
184	20.67	0 97	1.70	16.5	16 5	-83.5
243	10.51	0.49	1.66	8.1	8.1	-91.9
304	3 77	0.18	1.44	2.6	2 6	-97.4
Q leucotrichophora :						
Initial	100	4.55	1.10	50.1	—	0
62	55.19	2.51	1.17	29.4	58.7	-41.3
123	38.49	1.75	1.05	18.4	36.7	-63.3
184	29.80	1.36	1.02	13.9	27.7	-72.3
243	16 38	0.75	0.97	7.3	14.6	-85.4
304	5.47	0.25	0.88	2.2	4.3	-95.7
365	1.26	0.06	0.85	0.58	1.0	-99.0

Contd...

1		2	3		4	5
			PINE-MIXED BROADLEAF FOREST			
L. ovalifolia :						
Initial	100	4.68	1.27	52.4	—	0
62	45.52	2.13	1.21	25.8	43.4	-56.6
123	38.33	1.79	1.07	19.2	32.3	-67.7
184	31.10	1.46	1.01	14.8	24.9	-95.1
243	19.42	0.91	0.97	8.8	14.8	-85.2
304	14.02	0.66	1.03	6.8	11.4	-88.6
365	3.71	0.17	1.01	1.7	2.9	-97.1
Q. glauca :						
Initial	100	4.65	1.13	52.5	—	0
62	52.92	2.46	1.25	30.8	58.7	-41.3
123	30.62	1.42	1.14	16.2	30.9	-69.1
184	24.41	1.14	1 09	12.4	23.6	-76.4
243	20.14	0.94	0.89	10.6	20.2	-79.8
304	10.91	0.51	0.78	4.0	7.6	-92.4
R. arboreum :						
Initial	100	4.85	0.95	46.1	—	0
62	75.74	3.67	1.08	39.6	85.9	-14.1
123	63.57	3.08	1.23	37.9	82.2	-17.8
184	59.86	2.90	1.06	30.7	66.6	-33.4
243	55.22	2.68	0.90	24.1	52.3	-47.7
304	40 09	1.94	0.83	16.1	34.9	-65.1
365	27.59	1.34	0.91	12.2	26.5	-73.5
487	9 74	0 47	0.84	3.9	8.5	-91.5
578	4 54	0.22	0.81	1.8	3.9	-96.1
Q. leucotrichophora :						
Initial	100	4.55	1.10	50.1	—	0
62	68.92	3.14	1.04	32.7	65.3	-34.7
123	60.20	2.74	0.96	26.3	52.5	-47.5
184	51.30	2.33	0.88	20.5	40.9	-59.1
243	44.26	2.01	0.84	16.9	33.7	-66.3
304	27.74	1.26	0.83	10.5	21.0	-89.0
365	12.95	0.59	0.83	4.9	9.8	-90.2
487	2 55	0.12	0.80	1.0	2.0	-98.0

Contd...

1	2		3		4	5
			PINE FOREST			
P. roxburghii :						
Initial	100	4.52	0.51	23.1	—	0
62	80.48	3.64	0.59	21.5	91.9	-8.1
123	79.00	3.57	0.65	23.2	100.4	-0.4
184	73.31	3.31	0.66	21.8	94.4	-5.6
243	64.96	2 94	0.65	25.0	108.2	-8.2
304	55.88	2.53	0.95	24.0	103.2	-3.9
365	48.13	2.20	0.94	20.7	89.6	-10.4
487	33.71	1.52	0.90	13.7	59.3	-40.7
578	28.23	1.28	1.01	12.9	55.8	-44.2
730	7.56	0.34	1.01	3.4	14.7	-85.3
Q. leucotrichophora :						
Initial	100	4.55	1.10	50.1	—	0
62	75.52	3.44	1.03	35.4	70.7	-29.3
123	73.58	3.35	0.99	33.2	66.3	-33.7
184	71.96	3.27	0.91	29.8	59.5	-40.5
243	51.53	2.34	0.88	20.6	41.1	-58.9
304	41.26	1.88	0.76	14.3	28.5	-71.5
365	26.07	1.19	0.77	9.2	18.4	-81.6
487	13.36	0.61	0.76	5.1	10.2	-89.8
578	9.22	0.42	0.73	3.1	6.2	-9.83
			MIXED OAK–PINE FOREST			
Q. leucotrichophora :						
Initial	100	4.55	1.10	50.1	—	0
62	70.13	3.19	1.15	36.7	73.3	-26.7
123	64.40	2.93	0.97	28.4	56.7	-43.3
184	56.64	2.58	0.98	25.0	50.0	-50.0
243	45.85	2.09	0.95	19.9	32.7	-60.3
304	37.22	1.69	0.92	15.5	30.9	-69.1
365	23.62	1.07	0.88	9.4	18.8	-81.2
487	8.56	0.39	0.87	3.4	6.8	-93.2
578	3.27	0.15	0.84	1.3	2.6	-97.4

Contd...

1	2		3		4	5
M. esculenta :						
Initial	100	4.72	0.88	41.5	—	0
62	87.70	4.14	1.13	46.8	112.8	–12.8
123	87.68	4.14	0.93	38.5	92.8	–7.2
184	66.69	3.15	0.94	29.6	71.3	–28.7
243	61.97	2.92	0.85	24.8	59.8	–40.2
304	43.24	2.04	0.81	16.5	39.8	–60.2
365	26.84	1.27	0.73	9.3	22.4	–77.6
487	14.08	0.66	0.72	4.8	9.6	–90.4
578	7.96	0.38	0.70	2.7	6.5	–93.5
MIXED OAK-[redacted] FOREST						
Q. lanuginosa :						
Initial	100	4.64	1.24	57.5	—	0
62	75.78	3.52	1.35	47.5	82.6	–17.4
123	67.31	3.12	1.41	65.5	63.5	–36.5
184	62.52	2.90	1.17	33.9	59.0	–41.0
243	51.12	2.37	1.15	27.3	47.5	–52.5
304	41.42	1.92	1.03	19.8	34.4	–65.6
365	32.07	1.49	0.97	14.4	25.0	–75.0
487	12.09	0.56	0.97	5.4	9.4	–90.6
578	6.47	0.30	0.90	2.7	4.7	–95.3
Q. floribunda :						
Initial	100	4.67	1.32	61.6	—	0
62	76.35	3.57	1.43	51.1	83.0	–17.0
123	70.85	3.31	1.28	42.4	68.9	–31.1
184	65.33	3.05	1.40	42.7	69.3	–30.7
243	50.77	2.37	1.20	28.4	46.1	–53.9
304	43.23	2.02	1.15	23.2	37.7	–62.3
365	35.92	1.68	1.06	17.8	28 9	–71.1
487	13.12	0.61	0.01	6.2	10.7	–89.3
578	5.48	0.26	0.98	2.5	4.1	–95.9
Q. leucotrichophora :						
Initial	100	4.55	1.10	50.1	—	0
62	63.68	2.90	1.18	34.2	68.3	–31.7
123	51.82	2.36	1.16	27.4	54.7	–45.3
184	50.00	2.28	1.14	26.0	51.9	–48.1
243	41.36	1.88	1.05	19.7	39.3	–60.7
304	24.86	1.13	0.94	10.6	21.2	–78.8
365	12.87	0.53	0.94	5.0	10.0	–90.0
487	1.27	0.06	0.92	0.6	1.2	–98.8

philippinensis and *Q. leucotrichophora* showed faster release. All the four species placed for decomposition at the pine-mixed broadleaf site showed different patterns of a Ca release. Initial Ca release of *L. ovalifolia* was quite similar to the weightloss pattern and of *Q. glauca* closely paralleled the weightloss pattern throughout the study. Pattern of Ca release in *R. arboreum* was markedly different with weight loss upto 184 days, thereafter, a similar pattern of loss was obtained for Ca and total weight of litter. *Q. leucotrichophora* showed greater Ca release than weight loss througout the decomposition.

The pattern of Ca release and weight loss for *P. roxburghii* was distinctly different throughout the study period. However, the pattern of Ca release was similar to whight loss for *Q. leucotrichophora*, but throughout the time course of decay the former was always higher than the later. During the first annual cycle *P. roxburghii* released only 10.4% Ca, whereas 82% release occurred in *Q. leucotrichophora*. A net import of 0.37 and 0.71 mg Ca per litter bag was observed in *P. roxburghii* after 123 and 243 days, respectively. For both the species Ca release was always lower than the total weight loss.

At mixed oak pine forest site Ca release was lower than the weight loss in *Q. leucotrichophora* upto 62 days and in *M. esculenta* upto 184 days of litter incubation. In the later stages of decay Ca release was always higher than weightloss for both the species. *Q. leucotrichophora* showed faster release of Ca than *M. esculenta* throughout the decay cycle. The pattern of Ca release in *Q. leucotrichophora* closely followed that of the weight loss, whereas the release was slower than the loss of the organic matter in *Q. lanuginosa* and *Q. floribunda* upto 62 and 184 days, respectively. In the later periods the Ca release was faster than the decrease in weight loss.

Differences in the rate of decomposition among species of different forest sites have been reported by several authors including Wiegert and Mc Ginnis (1975), Maclean and Wein(1978), Gupta and Singh (1981), Pandey and Singh (1982, 1984) and Upadhyay and Singh (1985). Edwards (1977), while studying the decomposition of six leaf litter species, found that the species placed at ridge site decomposed slowly than on the valley sites. Ovington (1962) reported complete decay of temperate deciduous forest species in Britain in 6–9 months. Jenny *et al.* (1949) estimated a decomposition period of 28–60 years for communities of black oak and ponderosa pine, respectively at an altitude of 1500 m in California. McClaugherty *et al.* (1985) while studying the decomposition of conifer and broadleaf litters on black hawk Island in South Central Wisconsin found that in 2 years across the species weight loss ranged from 45–75%. The decomposition rate was slowest in Pine and hemlock needles compared to broadleaf species. De Catanzaro and Kimmins (1985) found only 40% loss in weight in conifer needles and 24–30% in broadleaf litters in 18 month of incubation in coastal British Columbia. On 17 sites, in Swedish pine forests, Meantemeyer and Berg (1986) found 12-42% weight loss in Scots pine needle litter in one year. While studying the decomposition in New Jersey pine barren. Boerner and Lord (1984) observed only 12.6% decomposition in mixed leaf litter for one annual cycle. In winter season generally slower weight losses were observed in all species except for *M. philippinensis, Q. leucotrichophora* (at pine forest site) *M. esculenta* and *Q. floribunda*. Slightly higher weight losses in these species during winter probably indicates that some initial weathering periods are required to promote subsequent decomposition. Also litter having sufficient moisture could not be adversely affected by low temperature of winter. Stark (1973) reported that in Jeffery Pine systems in Navada, moisture restraints during summer inhibited decomposition, while winter temperatures ameliorated by snow covers did not have equally an adverse effect. Gupta and Singh (1977), Crossley and Hogland (1962), Witkamp and Vander drift (1967), Wiegert and Mc Ginnus (1925), Seastedt *et al.* (1983) Pandey and Singh (1982) also found greater weight losses in summer and lowest in winter season in different habitats.

The immobilization of Ca in the decomposing litter probably is not related to metabolic demand for the element by fungal heterotrophs because Ca usually is not a limiting element for fungi. The Ca release from different forests of the present study can be compared to other works. Cromack and Monk (1975) found no release in Ca in *Pinus strobus* and 29% release in mixed hardwood litter in North Carolina U. S. A. in one annual cycle. Lemmee and Bichaut (1978) in France found 6% release in Ca in *Quercus petraea* after one annual cycle. Maclean and Wein (1978) while working on several species found 50% release in Ca in *P. banksiana* 38% in *Betula papyrifera*, 50% in *Acer rubrum* and 57% in *Prunus pensylvanica* after two years of decay cycle in New Brunswick, Canada. Goze *et al.* (1973) found 53% losses in *Betula allegheiensis*, 47% in *Fagus grandifolia* and in *Acer saccharum* after one annual cycle. Pandey and Singh (1984) while working in mixed oak conifer forest in Nainital (India) found 87% losses for *Q. leucotrichophora* 96% for *Q. floribunda*, 78% for *Cedrus deodara* and 82%for *Cupressus torulosa* after 487 days of litter incubation. It is probable that the differences in the release of calcium in differences in the release of calcium in different forest ecosystems of the world may be due to the differences in environment and substrate quality. The increase in absolute mass of Ca occurred in *P. roxburghii* and *Q. esculenta* only. Boerner and Lord (1984) and Fahey (1983) also found absolute increase in Ca in decomposing Pine litter. whether Ca is mineralized or immobilized in leaf litter depend on the initial C:Ca ratios with Calcium rich litters undergoing rapid mineralization while calcium is immobilized in Calcium poor litter. However, Will (1967), Attiwill (1968), Thomas (1970) and Gosz *et al.* (1973) have suggested that Ca is not susceptible to leaching and that the loss pattern of Ca is similar to the weight loss pattern of the leaf tissue. This indicates that decomposition was responsible for the majority of the Ca release to the ecosystems. In *P. roxburghii* increase in absolute mass of Ca occurred in winter period. It is probable that Ca was taken up from the forest floor by fungal heterotrophs translocated to the decomposing litter and deposited. According to Graustein *et al.* (1977) and Gromack *et al.* (1979), leaching does not occur in winter period and it may be essential for the fungal decomposers to form the sparingly soluble Calcium oxalate salt as a means of eliminating metabolic byproducts from their tissues.

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REFERENCES

Attiwill, P. M. (1967). The loss of elements from decomposing litter. *Ecology*, **49**: 142-145.

Boerner, R. E. J. and T. R. Lord (1984). First year loss of mass and nutrients from leaf litter in the New Jersey Pine Barrens *Bartonia*, 50 : 12-20.

Buoyaucos, C. J. (1951). A calibration of the hydrometer method for making mechanical analysis of oils. *Agron. J.*, 43 : 434-438.

Cromack, K., Jr. and C. D. Monk, (1975) Litter production, decomposition and nutrient cycling in a mixed hardwood watershed and a white pine watershed. In : *Mineral cycling in* South-eastern Ecosystems, (eds.) F. G. Howell, J. B. Gentery and M. H. Smith, pp. 609-624. NTIS, Springfield, Virginia.

Cromack, K., Todd, R. L. Todd and C. D. Monk (1975). Patterns of basidiomycete nutrient accumulation in conifer and deciduous forest litter. *Soil Biol. Biochem.*, 7 : 265-268.

Crossley, D A., Jr. and M. P. Hoglund (1962). A Litter bag method for the study of micro-arthropods inhabiting leaf litter. *Ecology* , 43 : 571-573.

Curtis, J. T. (1959). The vegetation of Wisconsin. An ordination of plant communities. Univ. of Wisconsin press, Madison 657 p.

DeCatanzaro, J. B. and J. P. Kimmins (1984). Changes in weight and nutrient composition of litterfall in three forest ecosystem types on coastal British Columbia. *Can. J. Bot.*, 63 : 1046-1056.

Edwards, P. J. (1977). Studies of mineral cycling in a Montane rain forest in New Guinea. II. The production and disappearance of litter. *J. Ecol.*, 65 : 971-992.

Fahey, T. J. (1983). Nutrient dynamics of aboveground detritus in Lodgepole pine (*Pinus contorta*) ssp *latifolia*) ecosystems, southeastern Wyoming. *Ecol. Monogr.*, 53 : 51-72.

Gosz, J. R., G. E. Likens and F. H. Bormann (1973). Nutrient release from decomposing leaf and branch litter in the Hubbard brook forest, New Hampshire. *Ecol. Monogr.*, 43 : 173-191.

Graustein, W. C., K. Cromack, Jr. and P. Sollins, (1977). Calcium oxalate : occurrence in soils and effect on nutrient and geochemical cycles, Science 198 : 1252-1259.

Gupta, S. R. and J. S. Singh [1977]. Decomposition of litter in a tropical grassland. *Pedo-biologia.*, 17 : 234-237.

Gupta, S. R. and J. S. Singh (1981). The effect of plant species, weather variables and chemical composition of plant material on decomposition in a tropical grassland. Plant and Soil., 59 : 99-117.

Issac, R. A. and K. D. Kerber (1971). Atomic absorption spectrophotometry. In : Instrumental methods for analysis of soil and plant tissues. L. M. Walsh (ed.) Science Society of America, Inc., Madison, WI 17-37 p.

Jenny, H., S. P. Gessel and F. T. Bingham. (1949). Comparative study of decomposition rates of organic matter in temperate and tropical regions. *Soil Sci.*, 68 : 419-432.

Kershaw, K. R. (1973). Quantitative and dynamic plant ecology. The english language book society and Edward Arnold Ltd., London. 308p.

Lemee, G. and N. Bichaut (1973). Recherches sur les ecosystemes des reserves biologique de la foret de Fontainebleau. II. Decomposition de la litiere de fenilles des arbres et liberation des bioelements. *Oecologia Plantanum*, 8 : 153-174.

Maclean, D. A. and R. W. Wein (1978). Weightloss and nutrient changes in decomposing litter and forest floor material in New Brunswick forest stand. *Can. J. Bot.*, 56 : 2730-2749.

McClaugherty, C. A., J. Paster, J. D. Aber and J. M. Melillo (1985). Forest litter decomposition in relation to soil nitrogen dynamics and litter quality. *Ecology*, 60 : 266-279.

Meentemeyer, V. and B. Berg (1986). Regional variation in rate of mass-loss of scots-pine needle litter in Swedish pine forests as influenced by climate and litter quality Scand. *J. For. Res.*, **1** : 167-180.

Misra, R. (1968). Ecology workbook, Oxford and IBH Publishing Co., Calcutta. 244 p.

Pandey, U. and Singh, J. S. (1982). Leaf litter decomposition in an oak-conifer forest in Himalaya : The effects of climate and chemical composition. *Forestry*, **55** : 47-59.

Pandey, U. and J. S. Singh, (1984). Nutrient changes and release during decomposition of leaf litter in an Himalayan oak-conifer forest. *Can. J. Bot.*, **62** (9) : 1824-1831.

Philips, E. A. (1959). Methods of vegetation study. A Hort-Dryden Book. Henry Holt & Co. Inc. 107p.

Piper. C. S. (1944). Soil and plant analysis. Interscience Publications Inc., New York.

Seastedt, T. R., D. A. Crossley, V. Meentemeyer and Waide, J. B. Waide. (1983). A two year study of leaf litter decomposition as related to macroclimatic factors and micro arthropod abundance in the southern Appalachians. *Hol. Ecol.*, **6** : 11-16

Stark, N. (1973). Nutrient cycling in Jeffrey pine Ecosystem. University of Montana, Missoula. 389p.

Swift, M. J., O. W. Heal and J. M. Anderson. (1979) Decomposition in terrestrial ecosystems. Blackwell Scientific Publications, Oxford.

Thomas, W. A. (1970). Weight and Calcium losses from decomposing tree leaves on land and in water. *J. Appl. Ecol*, **7** : 237-241.

Upadhyay, V. P. and J. S. Singh (1985). Nitrogen dynamics of decomposing hardwood leaflitter in a Central Himalayan forest. *Soil Biol. Biochem.*, **17** : 827-830.

Wiegert, R. G. and J. T. Mc Ginnis. (1975). Annual production and disappearance of detritus on three south carolina old fields *Ecology*, **56** : 129-140

Will, G. M. (1967). Decomposition of *Pinus radiata* litter on the forest floor. I. changes in dry matter and nutrient content. *N. Z. J. Sci.*, **10** : 1030-1044.

Witkamp, M. and J. Van der Drift. (1961). Breakdown of forest litter in relation to environmental factors. Plant and Soil, 15 : 295-311.

Wood, T. G. (1976). The role of termites (Isoptera) in decomposition processes. In : The role of terrestrial and aquatic organisms in decomposition processes (J. M. Anderson and A. Macfadyen, eds.) pp. 145-168. Blackwell Scientific Publications, Oxford.