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LITTER DECOMPOSITION AND NUTRIENT RELEASE PATTERN OF SOME PROMINENT TREE SPECIES IN THE COOL-TEMPERATE FORESTS OF THE NANDA DEVI BIOSPHERE RESERVE IN UTTARAKHAND, INDIA

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Abstract

The present study was conducted in the buffer zone of the Nanda Devi Biosphere Reserve, which is situated in the Himalayan highlands, biogeographic province-2B in India. The area is completely protected since January 7th, 1939, when it was declared as a sanctuary. Now it has been included in the list of 'World Heritage Sites', since 1992. The area is reputedly one of the most spectacular wildernesses having qualitatively as well as quantitatively a unique biota, cultural heritage, religious faith, climate and soil type in the world. Geographically it falls between 30^{0}17'N to 30^{0}41'N latitude and 79^{0}40'E to 80^{0}05'E longitude and makes headwaters of Dhauliganga and Rishiganga, tributaries of the National river Ganga, in Uttarakhand. The parent material mainly represents crystalline rocks and comprises garnetiferous mica, schists, garnet mica and mica quartzite. The soil under broad-leaved forests is usually dark black and deep due to the decomposition of a large amount of accumulated organic matter, while under coniferous forests, it is generally light and shallow, due to the presence of hard rocks in soils and a smaller amount of organic matter. Out of the 10 identified species and their composition,, the moisture holding capacity of litter observed in composite leaf litter (19.73%) was the highest and in the Cedrus leaf litter (8.20%)the lowest. The turnover rate (r) ranged from 0.61 in Cedrus leaves to 0.74 in A. caesium, J. regia and Q. semecarpifolia leaf litter. The turnover time (t) was lowest for J. regia and A. caesium (1.35) and highest for the Cedrus leaf litter (1.65).

Keywords: *litter fall; litter decomposition; nutrients; nitrogen; phosphorus; potassium*

Introduction

Litter production and its decomposition in the forest floor are two important natural processes, which determine the functional aspects of the forest ecosystems. The quantity, composition and subsequent decomposition of forest litter are of major importance for the study of primary production, energy flow, cycling of nutrients and their budgeting in ecosystems. Such types of studies caught the attention of the 'International Biological Programme' [1-6]. The status of knowledge about litter decomposition, nutrient release pattern and soil respiration in terrestrial ecosystems was reviewed [7].

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In context of the Himalayan ecosystems, the process of spatial or temporal conversion of forest floor resources to sustain food production for human beings is common practice. But with increased population of both human and livestock and their competing demands for finite land resources, the requirements of forest floor resources to sustain crop productivity are increasing. A reduction in the area of forests and the increase in the amounts being removed, threatens the health of forest ecosystems that produce these resources. Even though there are several studies on litter decomposition in that region [8-16] and bole wood removals are restricted, due to conservation, the amount of forest floor resources that are removed, such as leaf litters and small branches, is not known. The present study focuses on assessing the decomposition rates of leaf litters from prominent tree species in their respective environments, assessing the decomposition rate of mixed tree leaves in mixed forests and assessing the nutrient release patterns from the decomposing leaf litters.

Materials and Methods

Fallen leaf litters of the prominent tree species were collected in the month of December (lean period) by using polythene sheets. Those polythene sheets were randomly placed on the forest floor. After 2-3 days the freshly fallen leaf litter of each selected species was collected and categorized according to species. The moisture content was determined and the dry weight equivalent was measured for each species. The litterbag techniques [4, 7] were used for our leaf litter decomposition study. The litter bags were filled with 5g of air-dried leaf litter, and then randomly placed on the forest floor for a one-year study. Thus, a large number of litter bags of each species were made and laid down on the forest floor. Some bags were placed under the canopy of adjacent trees, some under dense canopy and some under open canopy regimes of the forests.

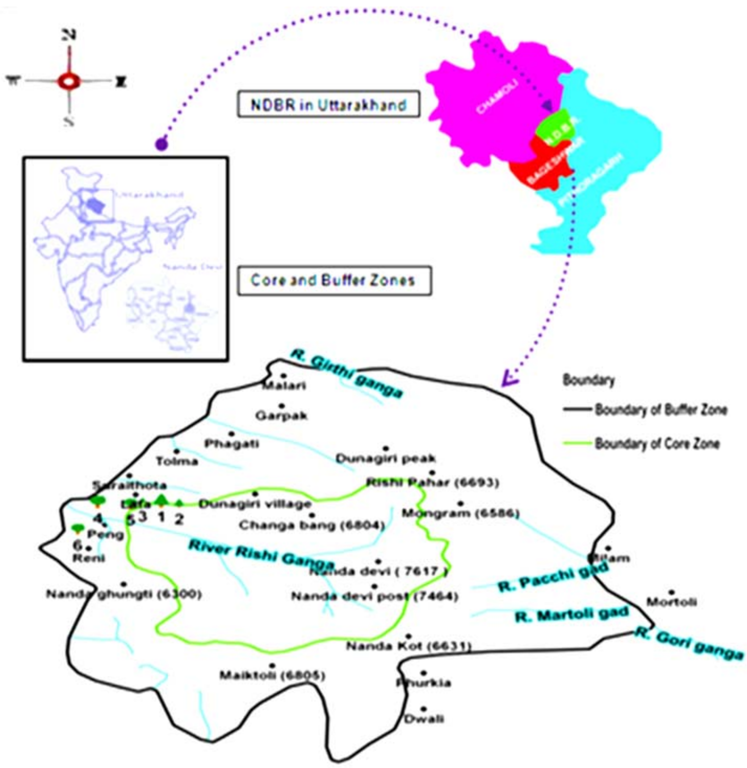

Fig. 1. Location map of the study area (Nanda Devi Biosphere Reserve).

Three bags of each species from different sites of each forest were to be retrieved after 30 days, but at the first sampling period, that was not possible, due to some unexpected circumstances (harsh climatic conditions in the study area). Thus, the first sampling of litter bags was done after 90 days and then at 30 days intervals for one year. The retrieved litter bags were processed in a laboratory and oven-dried at 70ºC until a constant weight of the samples was reached. The concentration of various nutrients, the turnover rate (k) and turnover time (t) of litter mass were calculated by the standard method [17]. The location of the study area with the selected forests is illustrated in figure 1.

Results and Discussion

Based on the phytosociological analysis of the selected forests in the buffer zone of the Nanda Devi Biosphere, we calculated the density (individuals ha^{-1}) of trees, shrubs and herbs. The characteristics of forest vegetation are shown in Table 1. The maximum moisture content in leaf litters was measured in composite leaf litter, under mixed forest (*Abies & Pinus* species*)*, followed by *Quercus semecarpifolia* (Kharsu) and *Cedrus deodara* (Deodar). The measured moisture contents are shown in Table 1. We observed that the needle shaped leaves have the least moisture content, followed by thin broad-leaves and thick broad-leaved species in the forests. The amounts of residual litter mass of the selected species are given in Table 2.

Table 1. Characteristics of the selected forests in the study area (Buffer zone of Nanda Devi Biosphere Reserve)

Ecological parameters	*A. pindrow* forest	*B. utilis* forest	*C. deodara* forest	Mixed Forest	*P. wallichiana* forest	*Q. semecarpifolia*
Elevation (m. asl)	2500-3000	>2800	2300-2500	2250-2500	2300-2500	2300-2500
Aspect	North	North	North	North	North	North-West
Slope (°C)	70°C	75°C	65°C	60°C	65°C	60°C
Tree density (tree/ha)	525	1415	1030	983	924	335
Shrub density (shrub/ha)	1118	1245	2449	1432	1342	1118
Herbs density (herb/ha)	4926	3233	7875	4620	5703	2526
Average height of Trees (m)	25 m.	20 m.	20 m.	20 m.	20 m.	15 m.
Basal area of (m/ha)	38.27	33.35	43.46	29.55	10.02	84.87
Top-canopy species	*Abies pindrow*	*Betula utilis*	*Cedrus deodara*	*Abies pindrow*	*Pinus wallichiana*	*Quercus* sp.
	Populus ciliata	*Abies pindrow*	*Pinus wallichiana*	*Pinus wallichiana*	*Cupressus* sp.	*Acer caesium*
Sub-canopy species	*Viburnum cotinifolium*	*Rhododendron* sp.	*Desmodium elegans*	*Viburnum* sp.	*Deutzia staminia*	*Viburnum* sp.
	Desmodium elegans	*Skimmea laureola*	*Nepeta discolor*	*Princepia utilis*	*Viburnum cotinifolium*	*Indigofera* sp.
Under storey species	*Bupleurum falcatum*	*Salvia glutinosa*	*Potentilla atrosanguinea*	*Cyperus niveus*	*Chenopodium botrys*	*Viola biflora*
	Viola biflora	*Anaphalis contorta*	*Polygonum affine*	*Galium* species	*Oxalis corniculata*	*Apluda mutica*

Table 2. Moisture content (%), annual decay constant (k), correlation between the % of residual leaf litter mass and nutrient concentration

Species with Vernacular Name	Eng. Name	Family (%±SE)	Moisture	Turnover Time *(t)*	Values		Nutrients			
					Rate *(R)*	*r & p*	N	P	K	Ca
Abies pindrow Royle: Ragha	Silver-Fir	Pinaceae	10.866±2.10	0.68	1.47	r	0.894	0.835	0.710	0.390
						p	>0.01	>0.01	>0.01	<0.01
Acer caesium Wall.: Kanchula	Maple	Aceraceae	16.287±2.153	0.74	1.35	r	0.977	0.922	0.959	0.984
						p	>0.01	>0.01	>0.01	>0.01
Betula utilis D. Don.: Bhojpatra	Silver-birch	Betulaceae	13.666±0.735	0.70	1.43	r	0.858	0.880	0.881	0.832
						p	>0.01	>0.01	>0.01	>0.01
Cedrus deodara Loud.: Deodar	Cedar	Pinaceae	8.207±2.953	0.61	1.64	r	0.965	0.971	0.938	0.892
						p	>0.01	>0.01	>0.01	>0.01
Juglans regia Wall.: Akhrot	Wild Walnut	Juglandaceae	14.193±0.720	0.74	1.35	r	0.924	0.936	0.854	0.889
						p	>0.01	>0.01	>0.01	>0.01
Pinus wallichiana Wall.: Kail	Blue-pine	Pinaceae	13.213±2.811	0.72	1.39	r	0.690	0.936	0.889	0.919
						p	>0.01	>0.01	>0.01	>0.01
*Populus ciliata*Wall.: Syan	Poplar	Salicaceae	16.266±2.641	0.69	1.45	r	-0.168	-0.139	-0.169	-0.152
						p	<0.05	<0.05	<0.05	<0.05
Quercus semecarpifolia Smith.Kharsu	White-oak	Fagaceae	19.300±1.441	0.74	1.35	r	0.965	0.953	0.968	0.877
						p	>0.01	>0.01	>0.01	>0.01
Taxus baccata Linn.: Thuner	Yew	Taxaceae	12.733±0.963	0.66	1.52	r	0.959	0.818	0.958	0.957
						p	>0.01	>0.01	>0.01	>0.01
Composite leaf litter	-	-	19.733±0.951	0.71	1.41	r	0.210	0.183	0.226	0.231
						p	<0.05	<0.05	<0.05	<0.05

Legend: (i) SE means standard error in data and (ii) r and p values refers to Correlation Coefficient (r)/(p) Significance Level

Among the conifer species, *Cedrus deodara* (Deodar) showed the lowest and *Pinus wallichiana* (Kail) showed the highest mass loss after 360 days of decomposition. Similarly, among the broad-leaved species, such as *Populus ciliata* (Syan) and *Acer caesium* (Kanchula) showed the highest mass loss after 360 days. The composite leaf litter under mixed forests (*Abies* and *Pinus* species) showed about 50% of initial mass loss after 360 days of decomposition.

Compared to other species, the composite leaf litter under the mixed forest (*Abies* and *Pinus* species) showed the highest release of nutrients after 360 days. Among the species studied, *Juglans regia* (Akhrot) showed the maximum release and *Populus ciliata* (Syan) showed the minimum release of nitrogen after 360 days of decomposition. *Abies pindrow* (Ragha) and *Taxus baccata* (Thuner) showed the lowest nitrogen release among the conifer species. The other two remaining conifers considered in the study (*Cedrus deodara* & *Pinus wallichiana*) showed a release of about 50% of nitrogen from the initial mass. Except for *Juglans regia* (Akhrot), all the broad-leaved species considered in the study showed a release of <22% nitrogen from the initial mass. It was >47% from the initial mass in all species studied with a maximum in *Abies pindrow* (81.30%) and *Juglans regia* (80.34%). The *Betula utilis* (Bhojpatra) is a prominent tree species in cool-temperate regions, near the timber line in the Himalayan region. It showed the lowest release of phosphorus during the 360 days of decomposition. The release pattern of phosphorus is prominent for *Abies pindrow* (Ragha), *Pinus wallichiana* (Kail) and for composite leaf litters during the first 90 days of decomposition. The *Juglans regia* (Akhrot), followed by composite leaf litter under mixed forests, showed the highest release in 360 days of decomposition. Te lowest was measured in *Populus ciliata* (Syan) leaf litter.

Among the conifers, *Abies pindrow* (Abies) and *Taxus baccata* (Thuner) showed <20% loss of initial mass, while the other two species (*Cedrus deodara* and *Pinus wallichiana*) showed a loss of about 40-45% of initial mass during 360 days of decomposition. Among the broad-leaved species, *Betula utilis* (Bhojpatra), *Quercus semecarpifoia* (Kharsu) and *Populus ciliata* (Syan) showed a loss of <24% of their initial mass, while, the other two species among those studied (*Acer caesium* and *Juglans regia*) lost approximately 43% and 66% of initial mass.. The release pattern during the 360 days of decomposition was highest in *Juglans regia* (Akhrot) and lowest in *Populus ciliata* (Syan). The release patterns of calcium for the other studied species did not show any pattern of variation between conifers and broad-leave species.

The concentration of nitrogen in the initial mass was lowest in *Pinus wallichiana* (Kail) and highest in *Abies pindrow* (Ragha). Similarly, the exchangeable phosphorus concentration in the initial mass of litter was lowest for *Acer caesium* (Kanchula) and highest for *Abies pindrow* (Ragha). The concentration of potassium was lowest in *Taxus baccata* (Thuner) and highest in *Acer caesium* (Kanchula) and the exchangeable calcium concentration was lowest in *Juglans regia* (Akhrot) and highest in *Quercus semecarpifoia* (Kharsu) .

The annual decay constant (k), turnover (t) and correlation coefficient of relationship between the remaining leaf litter mass and its nutrient concentrations for the studied species are listed in Table 2. All the nutrients showed a high correlation with their remaining mass, except for *Populus ciliata* (Syan) and composite leaf litter. The studied species showed turnover rate (k) values between 0.61 to 0.74, indicating that all species required more than one year for the complete disappearance of litter mass. Among the nine separate species and the composite litter, three broad-leaved species *viz, Acer caesium, Juglans regia* and *Quercus semecarpifolia* showed the lowest turnover rates (1.35), the highest were measured in *Cedrus deodara* (1.64), *Taxus baccata* (1.52) and *Abies pindrow* (1.47). The composite leaf litter under mixed forest (*Abies* and *Pinus* species) showed a turnover time of 1.41 years.

The decomposition rates of the leaf litter of different species we studied differed from one another. This may be related to the chemical composition of the leaf litters [18, 19] and the consequent differences in microbial activities. Soil moisture and the activities of soil microorganisms play a major role in determining how fast the litter disappears. The cool-temperate forests in the present study have limited moisture stresses. Nevertheless,, the levels of water vary greatly, the *Pinus wallichiana* (Kail) dominated forest is relatively dry with lower water holding capacity (%) and broad-leaved forest such as *Betula utilis* (Bhojpatra) dominated forest in the present study have high water holding capacity (%) and thus higher soil moisture for a longer time. Even though there was a perceivable difference in soil moisture between *Pinus wallichiana* (Kail) and *Quercus semecarpifolia* (Kharsu) forests, the turnover rates of leaf litters of these two species do not show much variation in their own forest environments.

The release pattern of various nutrients showed that the phosphorus released during decomposition faster than other nutrients. This suggests that susceptibility to rapid leaching is a major cause for the release of this nutrient, which is known to be relatively lower, compared to other temperate forests of the world [18]. An increased releases of phosphorus from litters during decomposition was also reported by A.G. Vandervalk and P.M. Attiwill [19].

The nitrogen contents of decomposing litter are known to increase due to fixation, absorption of atmospheric ammonia, through fall input and the immobilization by microbes during the first few months. As there was no observation during the first 90 days, it may be possible we missed such observations in the present study. The low levels of released nitrogen after 90 days of decomposition may be related to those processes. The release of other nutrients is also known to be slower during the winter months and this may have been the reason for the low release of nutrients for several of the species we studied.

The observations of the present study have great significance, as the forest floor leaf litters are removed during the post-rainy season or the early winter season and the faster release of phosphorus during the early decomposition of leaf litters on forest floors ensures that a significant amount is returned in the soil. It ensures that this nutrient, which is scarce in the ecosystems of the Himalayan region, is optimally recycled and that the health of the forest ecosystems is maintained.

The remaining quantity of decomposing leaf litter after the subsequent 30 days interval was shown in Table 3 and the percentage contribution of various soil texture classes under different depths of the selected forest soils is given in Table 4. The seasonal variation of nutrients under different depths of the selected forests is shown in Table 5.

Table 3. Remaining quantity (gm±SE) of decomposing leaf litter

Sampling period	Species selected for litter decomposition				
	Abies pindrow	***Acer caesium***	***Betula utilis***	***Cedrus deodara***	***Juglans regia***
0 Days (Initial mass)	4.456±0.105	4.187±0.109	4.316±0.037	4.589±0.148	4.290±0.036
90 Days	4.283±0.137	3.436±0.064	4.164±0.113	4.525±0.057	3.857±0.316
120 Days	3.921±0.258	3.207±0.043	3.497±0.321	4.296±0.046	3.739±0.313
150 Days	3.516±0.363	3.180±0.039	3.071±0.390	3.896±0.152	3.575±0.316
180 Days	3.166±0.384	2.930±0.117	2.917±0.348	3.686±0.163	3.409±0.341
210 Days	3.143±0.171	2.623±0.039	2.533±0.380	3.585±0.158	3.282±0.387
240 Days	2.978±0.165	2.440±0.057	2.483±0.318	3.484±0.153	2.182±0.128
270 Days	2.785±0.255	2.178±0.026	2.383±0.288	3.421±0.163	2.140±0.167
300 Days	2.619±0.384	2.005±0.020	2.290±0.250	3.345±0.178	1.996±0.296
330 Days	2.418±0.332	1.955±0.050	2.181±0.213	3.295±0.160	1.883±0.212
360 Days	2.368±0.769	1.780±0.050	2.112±0.258	3.210±0.050	1.781±0.269
Sampling period	***Pinus wallichiana***	***Populus ciliata***	***Q. semecarpifolia***	***Taxus baccata***	***Composite leaves***
0 Days (Initial mass)	4.339±0.140	4.187±0.132	4.035±0.072	4.363±0.048	4.013±0.047
90 Days	3.792±0.363	3.950±0.116	3.963±0.026	4.166±0.196	3.829±0.168
120 Days	3.261±0.183	3.737±0.277	3.526±0.037	4.012±0.214	3.711±0.195
150 Days	2.640±0.707	3.670±0.329	3.193±0.044	3.819±0.261	3.607±0.223
180 Days	2.529±0.327	3.636±0.211	2.868±0.044	3.271±0.156	3.470±0.273
210 Days	2.346±0.093	3.522±0.213	2.515±0.041	3.107±0.157	3.352±0.301
240 Days	2.253±0.039	3.452±0.161	2.324±0.032	3.079±0.135	2.552±0.242
270 Days	2.150±0.058	2.957±0.161	2.155±0.050	2.987±0.093	2.208±0.223
300 Days	2.033±0.044	2.900±0.115	1.963±0.119	2.897±0.155	2.165±0.216
330 Days	2.019±0.056	2.602±0.388	1.818±0.100	2.826±0.195	2.153±0.227
360 Days	1.957±0.413	2.252±0.124	1.736±0.171	2.583±0.142	2.010±0.142

Table 4. Percentage contribution of various soil texture classes under different depths of the selected Forests soils

Particle size	*A. pindrow* forest			*B. utilis* forest			*C. deodara* forest			Mixed forest			*P. wallichiana* forest			*Q. semecarpifolia*		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
4.75 mm	26.37 ±1.21	32.03 ±1.03	35.03 ±1.07	11.95 ±1.14	15.95 ±1.45	30.66 ±1.07	26.67 ±1.19	31.46 ±0.63	29.53 ±1.43	16.67 ±0.89	30.35 ±0.82	17.93 ±1.08	26.38 ±1.11	24.86 ±0.60	27.74 ±0.56	24.41 ±0.79	24.79 ±1.06	25.31 ±1.38
2.36 mm	3.69 ±0.34	4.17 ±0.27	4.71 ±0.59	4.82 ±0.32	4.95 ±0.60	6.54 ±0.28	3.90 ±0.08	3.28 ±0.24	2.98 ±0.36	3.26 ±0.32	4.38 ±0.29	4.54 ±0.26	3.82 ±0.29	3.20 ±0.38	5.61 ±0.61	4.42 ±0.28	4.64 ±0.28	9.43 ±1.52
1.18 mm	8.33 ±0.53	8.11 ±0.48	7.35 ±0.38	17.49 ±0.38	14.28 ±0.47	13.65 ±0.58	8.15 ±0.41	6.14 ±0.24	6.44 ±0.38	10.92 ±0.41	9.70 ±0.39	11.41 ±0.53	10.22 ±0.26	8.61 ±0.45	6.45 ±0.59	19.54 ±0.45	11.58 ±0.52	9.17 ±0.76
600 mic	8.74 ±0.53	6.26 ±0.37	6.83 ±0.44	17.45 ±0.57	14.47 ±0.86	10.36 ±0.47	8.70 ±0.20	6.26 ±0.36	6.38 ±0.46	15.71 ±1.03	7.53 ±0.15	10.59 ±0.51	11.51 ±0.68	7.51 ±0.41	6.19 ±0.54	9.24 ±0.52	10.46 ±0.49	9.95 ±0.60
300 mic	12.95 ±0.53	14.08 ±0.92	12.61 ±0.50	24.55 ±0.45	22.77 ±1.01	14.71 ±0.49	23.87 ±0.78	14.34 ±0.43	20.44 ±1.19	18.61 ±.0.93	14.39 ±0.77	24.27 ±0.41	26.50 ±1.22	21.23 ±1.58	17.17 ±0.65	18.73 ±1.06	19.28 ±0.80	18.40 ±0.86
100 mic	22.50 ±0.74	24.59 ±0.68	23.49 ±0.71	19.84 ±0.84	22.41 ±0.55	16.92 ±0.44	21.97 ±0.69	26.09 ±0.49	25.17 ±0.88	25.27 ±0.42	20.88 ±0.73	24.24 ±0.70	17.13 ±0.86	21.44 ±1.19	16.84 ±1.44	15.59 ±1.17	21.86 ±0.54	23.74 ±1.12
75 mic	11.99 ±0.29	8.36 ±0.71	7.65 ±0.21	3.21 ±0.56	4.31 ±0.35	5.12 ±0.21	5.64 ±0.36	9.13 ±0.18	6.79 ±0.66	6.39 ±0.80	8.52 ±0.60	5.73 ±0.31	3.53 ±0.36	9.26 ±0.65	12.14 ±0.26	6.33 ±0.60	6.00 ±0.47	3.61 ±0.64
< 75 mic	5.43 ±0.06	2.40 ±0.41	2.33 ±0.56	0.69 ±0.12	0.86 ±0.22	2.04 ±0.19	1.10 ±0.24	3.30 ±0.04	2.27 ±0.38	3.17 ±0.52	4.25 ±0.43	1.29 ±0.13	0.91 ±0.18	1.89 ±0.28	7.86 ±0.53	1.74 ±0.37	1.39 ±0.20	0.39 ±0.17
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Note: All values given in parenthesis (%±SE)

Table 5. Seasonal variation of nutrients under different depths of the selected Forests

Sampling period	*A. pindrow* forest			*B. utilis* forest			*C. deodara* forest			Mixed forest			*P. wallichiana* forest			*Q. semecarpifolia*		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
									Soil Moisture (SM)									
Mar., 98	52.21 ±2.29	58.42 ±3.91	77.66 ±1.19	84.74 ±2.33	73.75 ±1.75	72.56 ±3.84	48.78 ±1.62	52.69 ±1.16	54.66 ±0.54	55.28 ±2.55	61.46 ±2.22	73.44 ±2.47	42.28 ±3.85	58.51 ±4.06	69.93 ±2.25	62.23 ±0.85	73.54 ±2.05	78.04 ±1.19
Jun., 98	56.75 ±3.16	66.49 ±0.58	71.38 ±0.93	66.22 ±1.88	70.25 ±1.17	77.70 ±1.28	39.96 ±3.00	55.00 ±6.16	69.83 ±2.43	67.02 ±1.59	74.42 ±2.07	82.65 ±1.24	68.49 ±2.64	76.05 ±1.74	85.12 ±0.85	64.78 ±2.33	81.14 ±3.37	88.54 ±1.49
Sep., 98	28.11 ±1.57	31.62 ±0.62	38.56 ±0.48	27.10 ±0.35	33.91 ±1.08	42.44 ±0.89	17.92 ±1.74	24.14 ±0.94	30.49 ±0.11	34.24 ±1.01	37.53 ±0.69	41.57 ±0.50	20.26 ±1.30	26.27 ±0.78	30.92 ±0.42	67.72 ±1.32	72.22 ±0.58	75.37 ±0.61
Dec., 98	24.84 ±1.50	36.36 ±1.60	33.92 ±1.76	37.37 ±1.47	41.18 ±5.50	50.58 ±1.07	33.64 ±0.85	36.03 ±1.33	47.35 ±1.49	46.67 ±0.09	44.33 ±0.75	47.05 ±0.93	30.57 ±1.29	33.41 ±2.65	47.68 ±0.53	53.09 ±1.22	68.46 ±1.22	68.73 ±1.57
Mar., 99	52.40 ±0.76	56.87 ±1.76	64.95 ±1.80	82.50 ±1.31	78.37 ±0.74	74.06 ±0.80	47.98 ±0.69	55.49 ±1.94	63.24 ±0.65	56.58 ±0.98	50.71 ±1.49	63.39 ±1.64	42.58 ±0.83	50.70 ±1.05	59.73 ±1.32	59.88 ±1.34	68.18 ±1.26	61.43 ±0.73
									Organic Carbon (OC)									
Mar., 98	3.40 ±0.42	2.78 ±0.31	1.29 ±0.28	2.70 ±0.30	1.56 ±0.26	1.23 ±0.39	2.48 ±0.33	3.35 ±0.30	2.88 ±0.12	2.21 ±0.12	2.32 ±0.11	1.73 ±0.32	2.51 ±0.30	1.94 ±0.11	1.50 ±0.23	6.10 ±0.39	5.15 ±0.24	4.93 ±0.32
Jun., 98	3.32 ±0.09	2.19 ±0.72	1.92 ±0.12	3.38 ±0.39	1.04 ±0.29	0.81 ±0.24	1.47 ±0.28	2.24 ±0.08	1.05 ±0.10	4.32 ±0.08	3.40 ±0.12	1.34 ±0.03	1.88 ±0.04	2.24 ±0.05	1.24 ±0.09	3.25 ±0.03	2.36 ±0.05	1.19 ±0.05
Sep., 98	1.47 ±0.11	0.68 ±0.02	0.90 ±0.01	0.90 ±0.14	0.80 ±0.09	1.03 ±0.17	1.42 ±0.17	1.40 ±0.22	1.35 ±0.60	6.05 ±0.27	3.63 ±0.12	1.68 ±0.16	1.00 ±0.41	1.04 ±0.41	0.52 ±0.16	1.62 ±0.12	1.97 ±0.24	3.61 ±0.11
Dec., 98	3.50 ±0.09	0.71 ±0.05	0.52 ±0.13	1.75 ±0.76	1.52 ±0.73	1.33 ±0.71	3.36 ±0.17	1.52 ±0.05	1.39 ±0.05	3.29 ±0.09	2.81 ±0.03	2.81 ±0.31	0.79 ±0.06	2.95 ±0.02	2.28 ±0.18	2.75 ±0.03	1.17 ±0.08	2.94 ±0.06
Mar., 99	3.63 ±0.04	1.55 ±0.1	1.45 ±0.06	2.87 ±0.07	1.37 ±0.12	0.96 ±0.09	3.90 ±0.31	3.80 ±0.28	2.68 ±0.81	3.66 ±0.18	2.71 ±0.12	2.12 ±0.40	1.53 ±0.02	1.63 ±0.14	1.65 ±0.13	6.81 ±0.06	4.40 ±0.08	2.77 ±0.17
									Total Nitrogen (N)									
Mar., 98	0.189 ±0.0.24	0.177 ±0.020	0.168 ±0.018	0.133 ±0.019	0.094 ±0.006	0.089 ±0.014	0.211 ±0.024	0.100 ±0.010	0.028 ±0.005	0.211 ±0.015	0.072 ±0.005	0.072 ±0.005	0.205 ±0.015	0.072 ±0.015	0.028 ±0.005	0.211 ±0.015	0.122 ±0.015	0.067 ±0.010
Jun., 98	0.120 ±0.001	0.178 ±0.015	0.267 ±0.001	0.100 ±0.001	0.239 ±0.001	0.278 ±0.024	0.150 ±0.001	0.128 ±0.015	0.095 ±0.015	0.133 ±0.019	0.167 ±0.025	0.233 ±0.017	0.155 ±0.015	0.083 ±0.001	0.111 ±0.006	0.167 ±0.009	0.186 ±0.016	0.261 ±0.015
Sep., 98	0.266 ±0.017	0.228 ±0.015	0.172 ±0.020	0.283 ±0.020	0.211 ±0.015	0.161 ±0.015	0.200 ±0.020	0.133 ±0.001	0.072 ±0.001	0.200 ±0.001	0.122 ±0.011	0.100 ±0.001	0.183 ±0.014	0.157 ±0.005	0.056 ±0.006	0.211 ±0.006	0.178 ±0.005	0.100 ±0.009
Dec., 98	0.211 ±0.022	0.167 ±0.019	0.067 ±0.001	0.211 ±0.015	0.150 ±0.019	0.072 ±0.001	0.217 ±0.019	0.117 ±0.001	0.033 ±0.001	0.250 ±0.001	0.144 ±0.011	0.117 ±0.001	0.239 ±0.015	0.117 ±0.001	0.100 ±0.001	0.289 ±0.024	0.172 ±0.005	0.122 ±0.015
Mar., 99	0.150 ±0.017	0.111 ±0.011	0.100 ±0.001	0.178 ±0.024	0.133 ±0.00	0.117 ±0.001	0.244 ±0.030	0.155 ±0.022	0.022 ±0.001	0.250 ±0.001	0.133 ±0.019	0.133 ±0.038	0.167 ±0.019	0.189 ±0.029	0.084 ±0.017	0.261 ±0.034	0.139 ±0.015	0.117 ±0.001
									Available Phosphorus (P)									
Mar., 98	0.088 ±0.002	0.080 ±0.003	0.065 ±0.002	0.092 ±0.02	0.075 ±0.001	0.049 ±0.0007	0.072 ±0.003	0.058 ±0.002	0.047 ±0.002	0.077 ±0.002	0.058 ±0.003	0.056 ±0.002	0.081 ±0.002	0.071 ±0.001	0.047 ±0.002	0.082 ±0.001	0.084 ±0.002	0.084 ±0.002
Jun., 98	0.028 ±0.001	0.035 ±0.002	0.046 ±0.003	0.058 ±0.002	0.077 ±0.003	0.096 ±0.001	0.033 ±0.002	0.059 ±0.002	0.087 ±0.003	0.050 ±0.003	0.063 ±0.002	0.078 ±0.001	0.039 ±0.002	0.049 ±0.007	0.084 ±0.002	0.075 ±0.002	0.079 ±0.005	0.087 ±0.006
Sep., 98	0.079 ±0.002	0.085 ±0.002	0.092 ±0.002	0.095 ±0.002	0.082 ±0.002	0.075 ±0.005	0.092 ±0.002	0.074 ±0.002	0.058 ±0.002	0.079 ±0.004	0.064 ±0.002	0.039 ±0.003	0.056 ±0.003	0.047 ±0.003	0.030 ±0.003	0.085 ±0.002	0.078 ±0.001	0.083 ±0.002
Dec., 98	0.090 ±0.003	0.068 ±0.002	0.056 ±0.001	0.089 ±0.002	0.078 ±0.002	0.064 ±0.003	0.089 ±0.001	0.072 ±0.002	0.062 ±0.002	0.100 ±0.003	0.094 ±0.002	0.076 ±0.003	0.085 ±0.002	0.051 ±0.002	0.067 ±0.002	0.075 ±0.002	0.088 ±0.002	0.088 ±0.003
Mar., 99	0.089 ±0.001	0.076 ±0.001	0.058 ±0.002	0.096 ±0.001	0.086 ±0.002	0.074 ±0.003	0.070 ±0.005	0.059 ±0.001	0.051 ±0.001	0.099 ±0.008	0.061 ±0.002	0.053 ±0.002	0.083 ±0.002	0.072 ±0.002	0.059 ±0.002	0.085 ±0.002	0.082 ±0.001	0.082 ±0.002
									Exchangeable Potassium (K)									
Mar., 98	0.360 ±0.001	0.300 ±0.001	0.200 ±0.001	0.349 ±0.008	0.317 ±0.049	0.254 ±0.063	0.236 ±0.016	0.189 ±0.063	0.221 ±0.008	0.246 ±0.011	0.197 ±0.021	0.297 ±0.060	0.180 ±0.095	0.213 ±0.047	0.221 ±0.024	0.300 ±0.018	0.255 ±0.096	0.157 ±0.014
Jun., 98	0.179 ±0.036	0.234 ±0.017	0.358 ±0.049	0.179 ±0.036	0.234 ±0.017	0.247 ±0.009	0.189 ±0.024	0.228 ±0.007	0.257 ±0.045	0.246 ±0.001	0.246 ±0.010	0.357 ±0.024	0.129 ±0.036	0.142 ±0.014	0.168 ±0.024	0.176 ±0.007	0.299 ±0.024	0.251 ±0.014
Sep., 98	0.186 ±0.014	0.169 ±0.013	0.139 ±0.047	0.273 ±0.018	0.257 ±0.039	0.176 ±0.017	0.165 ±0.049	0.187 ±0.060	0.232 ±0.027	0.350 ±0.022	0.202 ±0.009	0.195 ±0.011	0.253 ±0.007	0.269 ±0.096	0.190 ±0.055	0.384 ±0.012	0.220 ±0.014	0.193 ±0.008
Dec., 98	0.223 ±0.018	0.230 ±0.072	0.168 ±0.013	0.124 ±0.013	0.175 ±0.016	0.190 ±0.009	0.223 ±0.018	0.168 ±0.008	0.133 ±0.060	0.209 ±0.010	0.145 ±0.007	0.115 ±0.009	0.217 ±0.011	0.195 ±0.035	0.099 ±0.020	0.357 ±0.019	0.303 ±0.015	0.229 ±0.024
Mar., 99	0.349 ±0.051	0.288 ±0.060	0.224 ±0.010	0.343 ±0.009	0.257 ±0.007	0.213 ±0.009	0.352 ±0.008	0.295 ±0.063	0.183 ±0.010	0.361 ±0.012	0.295 ±0.007	0.246 ±0.047	0.350 ±0.011	0.271 ±0.012	0.219 ±0.007	0.327 ±0.008	0.269 ±0.036	0.197 ±0.047
									Exchangeable Calcium (Ca)									
Mar., 98	0.89 ±0.01	0.92 ±0.03	1.22 ±0.02	0.77 ±0.08	0.87 ±0.01	1.24 ±0.001	0.85 ±0.001	0.89 ±0.001	0.95 ±0.01	0.97 ±0.01	0.99 ±0.001	1.26 ±0.001	0.79 ±0.01	0.83 ±0.001	0.96 ±0.001	1.12 ±0.001	1.19 ±0.001	1.26 ±0.01
Jun., 98	0.99 ±0.17	1.03 ±0.04	1.34 ±0.01	0.71 ±0.01	0.79 ±0.001	1.20 ±0.01	0.67 ±0.01	0.79 ±0.001	1.03 ±0.04	0.87 ±0.07	0.93 ±0.04	1.22 ±0.03	0.80 ±0.01	0.88 ±0.04	1.09 ±0.09	0.89 ±0.001	1.13 ±0.01	1.39 ±0.01
Sep., 98	0.95 ±0.01	1.17 ±0.05	1.23 ±0.01	0.95 ±0.01	0.98 ±0.01	1.27 ±0.03	0.78 ±0.001	0.84 ±0.001	1.00 ±0.01	0.86 ±0.06	0.93 ±0.001	1.33 ±0.001	0.88 ±001	0.89 ±0.001	1.17 ±0.001	0.96 ±0.01	1.25 ±0.01	1.48 ±0.01
Dec., 98	0.83 ±0.01	0.97 ±0.01	1.30 ±0.01	0.82 ±0.01	0.89 ±0.01	1.31 ±0.001	0.86 ±0.01	0.89 ±0.001	1.07 ±0.06	0.88 ±0.05	0.95 ±0.01	1.43 ±0.001	0.89 ±0.01	0.92 ±0.03	1.19 ±0.002	1.09 ±0.05	1.23 ±0.001	1.33 ±0.01
Mar., 99	0.93 ±0.03	0.95 ±0.01	1.26 ±0.01	0.79 ±0.01	0.88 ±0.01	1.18 ±0.001	0.87 ±0.01	0.94 ±0.001	1.43 ±0.01	0.94 ±0.001	1.13 ±0.01	1.19 ±0.01	0.77 ±0.01	0.90 ±0.03	0.99 ±0.001	1.11 ±0.01	1.15 ±0.01	1.20 ±0.001

Note: All values given in parenthesis (%±SE)

Conclusions

The present study is very important in the assessment of the tree leaf litter decomposition and nutrient release pattern in the natural ecosystems of the Himalayas. Such types of studies may be helpful to understand the nutrient release trend for a comparative assessment of forest ecosystems existing in areas with similar cool-temperate conditions and phyto-sociological features. Today, most of the scientists and scholars are paying great attention to the ecosystem services of the Himalayas, including carbon stock and its sequestration, the release of other nutrients, such as N, P, K and Ca etc. through the biomass directly added on the forest floor. Such types of litter decomposition and nutrient release patterns will be helpful for the assessment of ecosystem services in the protected areas of the Himalayas.

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