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Litter decomposition and nutrient cycling in temperate forest of Kumaun region

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Abstract

Background & Aim: The magnitude of litter fall and its decomposition in a forest ecosystem impart a crucial role in nutrient supply to plant as well as microorganisms. The present study was conducted to evaluate and compare the litter fall production, leaves litter decomposition and nutrient re-translocation among the dominant species i.e. Pine and Oak, of temperate forest of Kumaun region. **Results:** The estimated annual litter fall production was significantly 23% higher in Pine stand than Oak stand. The maximum portion of litter fall was occurred in summer and dry period between April-June. The nutrients concentration was higher in green leaves than leaves litter. Additionally, the nutrients concentration was found to be high in green leaves as well as in leaves litter of Oak species. The decomposition rate of leaves litter was found to high in Oak floor which is inversely proportional to the C/N ratio. The nutrient immobilization for all the nutrients was found to be high in Pine stand. The nutrient re-translocation percentage were in the order of P > K > N > Ca, in both the species that indicates the higher immobilization of phosphorous and potassium in the region. Soil status is also responsible for litter decomposition. The soil MBC, MBN, MBP, basal respiration and enzymes activity were higher in Oak stand which is directly correlated with the decomposition rate. **Conclusions:** Our results suggested that different plant species growing in same climatic condition differed in litter fall, litter decomposition and have different level of nutrients uptake and availability.
***Keywords**:* Litter decomposition; Nutrient cycle; retranslocation; *Pinus roxburgii*; *Quercus leucotricophora*

1. Introduction

The energy required by various ecosystem processes is mainly controlled and available from photosynthesis. Soil does not have capability to capture energy directly from sun i.e. solar energy because of the lack of photosynthetic organisms and depends on the energy rich bodies mainly produced by plants residues. These plant residues are decomposed by a series of naturally occurring biological processes that involve both microbial flora and fauna. Litter fall from leaves and other part of plants is the basic character of all vegetative environments, the vital source of nutrients and the beginning point of nutrient cycle. It is the main pathway through which organic matter and nutrients returns to the soil surface, where it composes the major portion of nutrients available to soil, incorporation with roots turnover[1, 2]. The availability of nutrient to the soil reflects the rate of decomposition and microbial activity[3]. Litter fall along with roots composes a major segment of nutrient cycling between plants and soils, thus internal fluctuations of C, N and P at ecosystem level are constrained by the available litter fall[4, 5]. The nutrients availability in any given soil system is mainly because of the decomposition dynamics of organic matter. The major part of carbon and the energy that enters the food web is detritus based litter that are used by the heterotrophic organisms and act as a nutrient reservoir in the food web. Plant litter production and decomposition is a crucial ecosystem process that defines and governs the plant-soil relationships by regulating the nutrient turnover and the buildup of soil organic matter. In fact, recycling of nutrients through decomposition is the primary source of available nutrients for plants in most unmanaged terrestrial ecosystems[6]. In contrast, the ecosystem existence is based on the decomposed matter. The rate of decomposition and the nutrient releases are highly influenced by the tree species through different properties, such as magnitude of litter produced, litter

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quality and nutrients release as well as climatic conditions and existing microbial communities in the soil system[7].

Forests worldwide are known to be significantly important habitats acts as a storehouse of biodiversity. These forests are the source of a major part of global terrestrial carbon in which temperate forest ecosystem plays major role in carbon sequestration from increasing atmospheric carbon dioxide, as it covers the major portion of terrestrial land. The productivity and the functioning of a forest are mainly influenced by the pattern and the rate of nutrient cycling. In a forest ecosystem, litter fall and its decomposition act as a clogged system which evidently interrelated with the cycling of nutrients; it regulates the nutrients and energy flow between biological components and soil, fixes energy and governs the overall growth and productivity of forest[8, 9].

The magnitude of nutrient re-translocation and the nutrient use efficiency in litterfall is the key source of nutrients for plants as well as used as an indicator of soil nutrient status[10]. Along the same climatic conditions, different plant species respond differently in their nutrient release pattern. The re-translocation of nutrients and their movement via soil and leaf litter is characterized as one of the important process in nutrient dynamics that are prominently used by plants to conserve nutrients.

Numerous studies have been documented on various features of litter fall in different forest ecosystem all over the world as well as in India. However, the information regarding different aspects of litter fall for temperate forest of India is still limited. The present study is undertaken in Nainital district of Kumaun region located in Uttarakhand. The forest covers a diverse range of plantation[11]. The main objective of the study is to examine the ability of two dominant plant species of the region in their litter fall creation and litter decomposition under same environmental condition and their impact on nutrients availability and uptake.

2. Methods

2.1 Site description

The study was conducted in the unprotected forest of Nainital district, located in Uttarakhand. The pine *(Pinus roxburgii)* and oak *(Quercus leucotrichophora)* are the two most dominated plant species of the region. The selected area is divided into two stands on the basis of dominant plant species. The stand dominated with pine plantation is surrounded between E 079° 32' 22.9", N 29° 23' 24.4" and at elevation of 1822m. Similarly, oak dominated stand is lie within E 079° 33' 08.3", N 29° 21' 15.9" and at elevation of 1333m. The vegetative structure of the region has been described by *Singh* and *Singh*, 1986 [12]. The climate is summer monsoon with three distinct season categorized into summer, which is warm and dry (March-May), rainy season is warm and wet (June-September) and the winter is cold and moderately dry (October-February). The minimum temperature ranges from -3 °C to 12 °C during the month of January and the maximum temperature fluctuates from 18 °C to 30 °C in the month of June. The average annual rainfall is 151.9mm (Figure. I). The soil is generally brown in color with 58.22%, 11.33% and 30.45% of sand, slit and clay respectively.

2.2 Litter fall collection

To study litter input in the selected forest stands i.e. Pine and Oak forest, five litter traps were randomly placed in each stands within the established plots of 10X10m^2. The litter accumulated within the traps was collected at regular interval time period for two consecutive years i.e. Oct, 2012 to Sep, 2014. Litter samples were taken to the laboratory oven dried at 60 °C and then weighed. The green leaves/needle samples of Pine and Oak were also collected at the same time.

2.3 Chemical analysis

The dried leaf litter and the green leaves samples were then processed for chemical analysis. The carbon content was measured by loss of ignition method. The nitrogen content was determined using Kjeldahl method[13]. Carbon content was measured by loss of ignition method. Stannous chloride method[14] followed by hot plate digestion in HNO_3:$HClO_3$ (3:1) at 180 °C for 6 h was used for phosphorous and potassium concentration.

2.4 Litter decomposition

The litter decomposition rate was estimated using nylon bag technique. A total of 50 litter bags (25 bags for each stand) were prepared. Each Litter bag of 20X20cm (5mm mesh) was filled with 10gm of air dried weighed of litter sample and placed on the forest floor in October, 2012. The litter bags were drawn at fixed interval of time during the study period. After collection, the extra

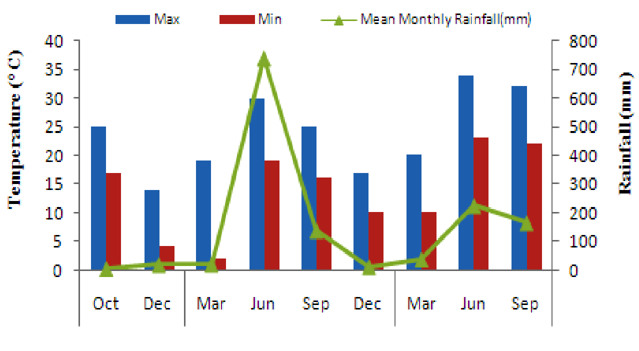

Figure I: Rainfall and temperature from Oct, 2012 to Sep, 2014 in the experimental site (Source: India Meteriological Department Site)

residual material was removed and the wet weight of the remaining litter sample was measured. The samples were then oven dried at 60 °C and reweight until constant weight achieved.

2.5 Soil study

Soil samples were randomly collected from each plot at a depth of 0-10cm and were taken to laboratory for analysis. The samples were then air dried, grounded and sieved using 2mm mesh screen. Soil pH was measured by the Orion star ion analyzer using soil:distilled water (1:2.5). Total organic carbon was analyzed using method proposed by *Walkey* and *Black* method[15]. Available and total nitrogen was estimated using *Stanford* and *smith*[16] and Kjeldahl method, respectively. Available and total phosphorous was assessed using *Olsen* method[17] and stannous chloride method[14]. Available potassium was determined by flame photometric method[18].

Soil microbial biomass carbon, nitrogen and phosphorous (MBC, MBN and MBP) was estimated using chloroform fumigation extraction method. Final MBC, MBN and MBP were calculated by difference between fumigated and non-fumigated values with a conversion factor of 0.33 for MBC, 0.54 for MBN and 0.40 for MBP.

Soil basal respiration was determined by alkali absorption method that quantifies CO_2 evolution using moist soil sample[19]. Soil enzyme assay were perform in moist soil. Acid phosphates and β-glucosidase activity was measured using *Eivazi* and *Tabatabai* [20, 21]. Dehydrogenase activity was assayed by *Pepper* et al. [22] method. Protease activity was estimated using *Ladd* and *Butler* [23] protocol. Fluorescein diacetate (FDA) activity was measured using method proposed by *stubberfield* and *Shaw*[24]. Cellulase activity was quantified using *Schinner* and *Von Mersi* method[25].

2.6 Data analysis

The remaining dry mass for each period was calculated using the weight of litter at each sampling period and the initial weight using the formula:

$$\% RM = (W_t/W_0) \times 100$$

Where, W_t = Weight (W_t) of litter at each sampling period (t)

W_0= Initial mass

Decomposition rate constant (k) of each single species was calculated by the most widely used single exponential decay model from the changes of litter dry mass over time[26]:

$$\ln (W_t/W_0) = -kt$$

Where, W_t = Amount of litter at time t

W_0 = Initial mass of litter

k = Decomposition rate constant

t = Elapsed time ($year^{-1}$)

The nutrient re-translocation efficiency (NRE) was computed by the equation given by *Finzi* et al.[27].

$$NRE\ \% = \{(A - B) / A\} \times 100$$

Where, A= Nutrient in green leaves

B= Nutrient in leaf litter

Nutrient use efficiency (NUE) was calculated according to *Vitousek*[28].

NUE=Litterfall mass/Nutrient content in litterfall

The values were expressed in g m^{-2} yr^{-1}.

Data were summarized as mean ± SD (standard deviation). Values were analyzed by Student's t test to determine the significant difference among the two stands in term of litterfall production, decomposition rate and the nutrient uptake. Soil samples were also analyzed for the significant difference among the two stands. A two-tailed (α=2) p value less than 0.05 (p < 0.05) was considered to be statistically significant.

3. Results and discussion

3.1 Litter fall

Under the same climatic condition, the composition of tree species plays an important role in litter production[29]. The two plant species found to be different in the quantity of litter biomass production. The mean annual litter fall biomass was 687.22 and 527.74 g m^{-2} y^{-1} in Pine and Oak, respectively (Figure. IIb). A significant difference (p<0.05) was found among the litter fall production by the two species. The litter fall at Pine stand is computed 23% higher than Oak stand. The maximum portion of litter fall biomass was observed in summer during April-June (Fig. IIa), which is characterized as dry period, and the result is in agreement with others result[30, 1]. To have a better understanding of nutrient cycling, forest growth, successional pathways and interactions with environmental variables in forest ecosystems the evaluation of litter fall production is needed. Climate, season, substrate quality and type of vegetation vary with varying litter production[31, 32].

3.2 Nutrient Status

The nutrient index in green leaves and leaf litter were found to be significantly different (p<0.05) in both the species. The nutrient concentration of N, P, K and Ca in green leaves and leaf litter were outlined in (Figure. IIIa). The variation in nutrient quality is mainly because of varied plant species differ in nutrient quality. The concentration of P, K and Ca in green leaves of Pine was recorded 0.54 mg g^{-1}, 2.15 mg g^{-1} and 12.14 mg g^{-1}, wheras the values in leaf litter were 0.32 mg g^{-1}, 1.37 mg g^{-1} and 8.69 mg g^{-1}, respectively. Similarly, the P, K and

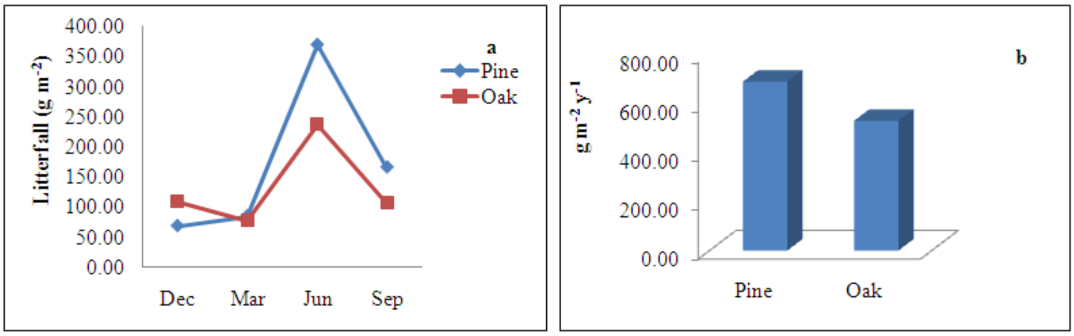

Figure II: (a) Litterfall pattern and (b) Total Litterfall in Pine and Oak stands (g m^{-2} yr^{-1})

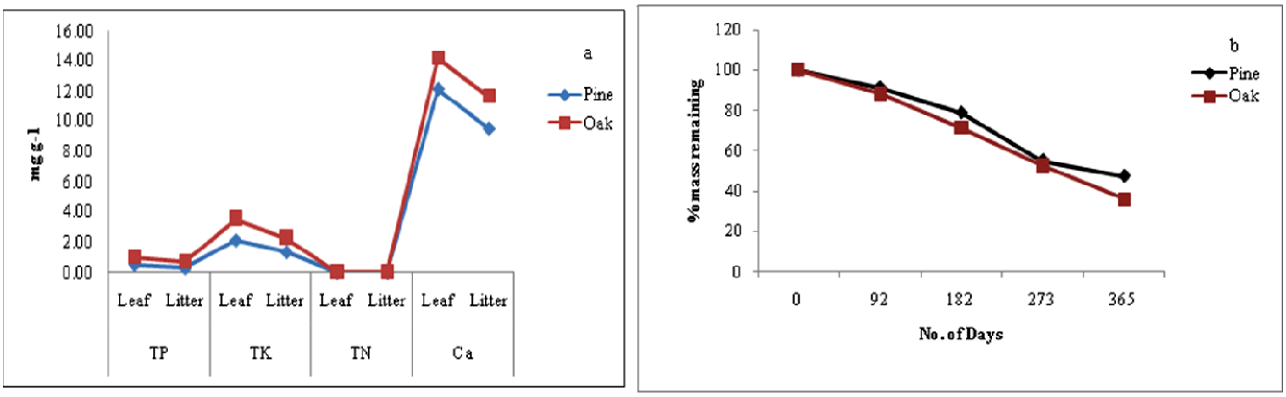

Figure III: (a) Nutrient concentration in green leaf and leaf litter of two plant species (mg g^{-1})
(b) Percentage of remaining mass at Pine and Oak stands during the study period

Ca concentration in Oak was 0.99 mg g^{-1}, 3.56 mg g^{-1} and 14.20 mg g^{-1} for green leaves and 0.58 mg g^{-1}, 2.29 mg g^{-1} and 10.36 mg g^{-1} for leaf litter, respectively. The nitrogen (%) in Pine was recorded 0.025% and 0.018% in green leaves and leaf litter. For Oak, the % nitrogen was found to be 0.030 and 0.024 in green leaves and leaf litter. Additionally, the Oak litter found to be low C/N ratio than that of Pine litter i.e. 16.78 and 21.84. This C/N ratio is a good indicator of decomposition process. A significant variation ($p < 0.05$) has been observed among all the mobile nutrients between leaf litter and green leaves. The concentration of all the nutrients was found to be low in leaf litter than the green leaves in both the plant species. The two plant species have different traits displayed species-specific variation in nutrient pattern. The plant species induced variation in chemical composition which directly affects the microbial attributes residing in that particular soil and influences the decomposition of organic matter as well as the physico-chemical status of soil[3, 33].

3.3 Litter decomposition

The rate of decomposition is highly influence by litter quality. The litter decomposition was found to be positively correlated with the time elapsed ($r = 0.98$, $p < 0.05$). The mass remained at the end was 47.6% and 36.2% for Pine and Oak, respectively (Figure. IIIb). The calculated annual decomposition rate of Pine and Oak litter was 0.74 and 1.01. The Pine litter has comparatively slower rate of decomposition than the Oak litter residing under same climatic condition. Pine litter with low nitrogen content and high C/N ratio results in significantly slower decomposition than Oak litter, that ultimately responsible for low weight loss % at Pine stand. The results are adjacent with other studies which have reported significantly positive correlation between C/N ratio and litter decomposition[34, 35]. The difference in the litter quality and the decomposition rate between the two stands dominated with two different plant species is mainly due to the difference among the substrate quality. Few literatures have demonstrated that stands with higher nutrient pool exhibit faster decomposition of litter[3]. Additionally, the efficient nutrient use efficiency is primarily described by lower nutrient concentration in litterfall[28]. The nutrient use efficiency of the selected species specific-stands of temperate forest of Kumaun region is presented in (Fig. IVa). The nutrient i.e. N, P, K and Ca use efficiency was found to be high at Pine dominated stand. Statistical analysis revealed a significant difference ($p < 0.05$) among the nutrient use efficiency of the two species. The nutrient used efficiency is inversely related to the availability of these entire nutrients in soil. Since, it is indirectly act as an indicator of soil nutrient availability while directly related to the decomposition rate[36]. Both the litter decomposition and the nutrient use efficiency are

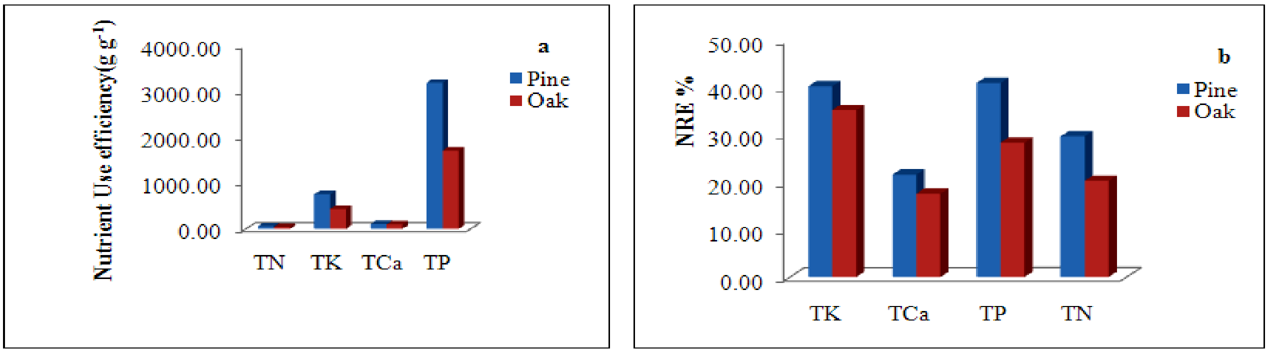

Figure IV: (a) Nutrient Use Efficiency of two different plant species and (b) Nutrient retranslocation efficiency of selected plant species

Table I: Soil physico-chemical characteristics under Pine and Oak plantation in the study area

Soil Characteristics	Pine stand	Oak stand
pH	5.687±0.015	5.867±0.031
TOC (%)	5.730±0.080	7.080±0.130
TN (%)	0.232±0.009	0.555±0.001
AN (%)	0.065±0.005	0.071±0.005
TP (mg g^{-1})	0.174±0.004	0.400±0.003
AP (mg g^{-1})	0.009±0.001	0.034±0.001
AK (mg g^{-1})	0.150±0.001	0.267±0.002
ACa (mg g^{-1})	1.067±0.003	1.770±0.003
C/N	24.72±1.26	12.75±0.28

influenced by various factors including litter composition, soil physico-chemical and biological properties. Numerous studies have suggested that recalcitrant like lignin, phenolics, tannins etc are also the chief composition of litterfall that suppresses the decomposition rate[37, 38]. However, these parameters are not examined in the present study and needs to be investigated further.

3.4 Nutrient retranslocation and cycling

The retranslocation efficiency of nutrients for *Pinus roxburgii* and *Quercus leucotricophora* was represented in (Fig. IVb). A significant difference ($p < 0.05$) was observed in nutrient retranslocation of (N, P, K and Ca) among the two species. The retranslocation percent of N, P, K, Ca were 29.27%, 40.97%, 40.26% and 21.62% in Pine whereas in Oak the percentage of these nutrients were 20.31%, 28.37%, 35.26% and 17.61%, respectively. Several authors have also demonstrated thar different tree species have differed in their nutrients retranslocation[39, 40]. The efficient retranslocation of the essential nutrients is the most significant characteristic of the climax phase of any forest ecosystem[41]. The retranslocation efficiency of phosphorous and potassium was recorded high among both the species suggested the higher remobilization of the phosphorous and potassium in the temperate forest. Furthermore, the NRE % of all the nutrients was found to be high in Pine species indicates comparatively lesser nutrient supply and soil nutrient deficient condition than that of Oak. However, the degree of retranslocation depends on its physical properties as well as their requirement by the plant. The lower NRE% in Oak species represents the lower proportion of nutrients returns to litterfall. The retranslocation with the reduction in restoration of nutrients by leaves litter, results in independence of the ecosystem with respect to soil and also a possibility of managing the available elements in timed way[42]. The difference in nutrient retranslocation is governed by several factors including plant growth, Plant species, plant age, site characteristics etc[43]. Additionally, these responses are also dependent on the eco-physiological response of tree species with the site environment and are the strong indicator of soil fertility[44].

3.5 Soil nutrient status

The pH of both the stands was recorded acidic in nature. The detailed description of soil nutrient status of both the stands was presented in (table I, II). The nutrient status of Oak stand is found to be significantly superior to Pine stand. Significant differences ($p < 0.05$) were recorded between the two stands except AN ($p > 0.05$). The C/N ratio is comparatively high at Pine stand which is mainly related to decomposition rate and pattern of nutrient immobilization. The decrease in value reveals increase in decomposition process. Soil Microbial biomass (Carbon, nitrogen and phosphorous) and basal respiration was higher at Oak stand as compared to Pine stand. Furthermore, the Oak stand displayed higher enzymes activity than Pine stand. There is significant difference recorded among the values of all the enzymes between the two stands. The higher microbial biomass and enzymatic activities at Oak stand suggested the higher availability of nutrient at Oak stand than that of Pine stand. The plants grow within nutrient-poor soil

Table II: Soil microbial characteristics enzymatic activities under Pine and Oak plantation in the study area

Microbial Characteristics	Pine Stand	Oak Stand
MBC(μg g^{-1})	335.20 ± 2.42	448.22 ± 2.31
MBN(μg g^{-1})	72.80 ± 1.51	91.38 ± 2.18
MBP(μg g^{-1})	34.47 ± 1.60	62.17 ± 1.54
Basal respiration (μg CO_2 g^{-1} soil hr^{-1})	23.22 ± 0.21	25.54 ± 0.21
Enzymes Assay		
Acid Phosphates	2287.70 ± 44.64	3235 ± 121.70
β-Glucosidase	586.34 ± 20.52	1621.78 ± 70.03
DHA	224.79 ± 13.53	623.09 ± 8.88
Protease	3702.48 ± 39.00	4022.73 ± 41.00
Cellulases	0.40 ± 0.02	0.73 ± 0.03
FDA	356.05 ± 6.63	491.77 ± 24.15

MB(C), MB(N), MB(P)-Microbial Biomass (Carbon), (Nitrogen), (Phosphorous)., DHA-Dehydrogenase., FDA-Fluorescein diacetate.

displayed high nutrient resorption resultant to low litter quality and decomposition rates[45] that leads to the lower magnitude of nutrient return to soil and litter. It has been observed that broad leaved tree may change the forest microenvironment in order to have faster decomposition and this was in favor of oak dominated stand where microbial activity is high[46, 35].

4. Conclusion

The study emphasizes that the two plant species differ in litterfall plants displayed different rate of decomposition. Also, the retranslocation of nutrients influenced not only by litter decomposition but also by the soil properties as well as plant nutrient status. It has been concluded that the high enzymatic activity and microbial biomass at Oak stand signifies that the availability of nutrients was higher at Oak stand than the Pine stand. Additionally, the Pine stand was undersupplied nutrient ecosystem characterized as high nutrient use efficiency and re-translocation of nutrients, lead to the depletion in litter quality as well as decomposition rate on the floor of Pine stand. Furthermore, the nutrient status of leaves, litter and soil play equal role in the working of nutrient cycle and the survival of forest ecosystem.

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Conflict of interest

The author's declares none.

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