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NEEDLE LITTER DECOMPOSITION AND NUTRIENT RELEASE IN SUB-TROPICAL PINE FOREST OF MANIPUR, NORTH-EAST, INDIA

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ABSTRACT

*A faster rate of needle litter decomposition of Pinus kesiya occurred in forest site I (undisturbed) with losing 98% of the initial mass in comparison with 96% of mass loss for forest site II (disturbed) over 24 months. Decomposition rate shows seasonal changes with the maximum rate in rainy season and minimum in dry winter season. Needle litter of forest site I exhibited higher initial concentration of nitrogen, cellulose and lower lignin and lignin to nitrogen ratio than forest site II. The rate of decomposition was correlated with soil moisture (r = 0.51**, 0.51**); soil temperature (r = 0.55**, 0.52**) than rainfall and mean air temperature in both forest sites. Chemical composition like initial nitrogen, lignin, lignin to nitrogen ratio and cellulose were significantly correlated with remaining biomass. (r = 0.78, 0.95, 0.95 and 0.81) in forest site I and (r = 0.62, 0.90, 0.91 and 0.75) in forest site II at the level of P < 0.01 in both forest sites. The decay constant were 0.594 and 0.582 in forest site I and site II respectively. During decomposition, concentrations of nitrogen and phosphorous were found to increase whereas potassium and sodium exhibited decreasing pattern from the original concentration in both the forest sites. The average concentration of nutrients in both forest sites was in the order N > K > P > Na. The release of nutrients (N P K and Na) based on the amount of element remaining over two years in forest site I and forest site II was in the order K>Na > P > N.*

KEY WORDS : *Pinus Kesiya, Needle Litter, Decomposition, Nutrient Concentration, Nutrient Release, Lignin, Cellulose And North-East India (Manipur).*

1. INTRODUCTION

Decomposition of litter is an important process in most terrestrial ecosystems because of its role in regulating building up of soil organic matter, releasing of nutrients for plant growth and influencing carbon flux from soil (Wardle *et al.*, 2003; Ganjeguente *et al.*, 2004). The decomposition of needle litter can be divided into two phases. In the first phase, decomposition rate is regulated by the concentration of nutrients in the litter and lignin decomposition rate in the second phase (Berg and Staaf, 1980). Leaf litter, which accounts for a large proportion of dead organic matter (~70%) (Costa et al. 2020), is the major source of nutrients and energy for heterotrophic communities in forest soil (García-Palacios et al. 2016a; Jia et al. 2018)

Decomposition and nutrient release rates are influenced by its resource quality, the activity and composition of soil organism and the physical micro-environment (Meentemeyer, 1978; Seastedt *et al.*, 1983; Finzi *et al.*, 2001; Gonzalez and Sealedt, 2001; Bradford *et al.*, 2002; Arunachalam & Singh, 2004; Goma & Bernhard, 2006). Resource quality includes N concentration, C - N ratio, lignin concentration, lignin to nitrogen ratio, soluble polyphenols and polyphenol - nitrogen ratios (Berg and Staaf, 1991; Mellilo *et al.*, 1982; Palm and Sanchez, 1991; Constantinides and Fownes, 1994; Mtambanengwe and Kirchmann, 1995). Under the influence of the prevalling elimatic environment, different litter have their own specific rate of decomposition which govern the rate at which nutrients are released from litter. The dynamics of the nutrients during decomposition of litter is complex because the nutrients often occur in different forms and are subject to various transformation.

High contents of lignin have a rate reducing influence on litter decomposition both in the early and later stages particularly when associated with high N content (Berg and Ekbohm, 1991; Couteaux *et al.*, 1995). Never the less a high nitrogen content generally regulates the early stages by enhaching the growth of microorganisms that degrade labile compounds and repress the form action of lignolytic enzymes (Keyser *et al.*, 1978). The role in cellulose and lignin is regulating factors of litter decomposition rate in temperate, boreal coniferous and deciduous forest (Mc Claugherty and Berg, 1987; Berg *et al.*, 1996; Couteaux *et. al.*, 1998).

Objective : To Evaluate

1. the rate of needle litter decomposition,
2. the release of nutrients (N, P, K & Na) and
3. the release rate of lignin and cellulose in bimonthly intervals of pine forest site I and forest site II.

2.MATERIALS AND METHODS

2.1. Site Description

The present investigation was conducted in two sub-tropical pine forest ecosystems of Imphal west district, Manipur (India) which falls under Eastern Himalayan region. The pine forest of Engel Ching (Engel Hill) is an undisturbed site (Forest site I) located near Tendongyan village and it falls at $24^0 55'$N latitude

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and 93⁰55′E longitude at an altitude of 895m from the mean sea level. The another pine forest is disturbed site (forest site II) extending on the Langol hill ranges near the Khamaran village which lies at 24⁰52′N latitude and 93⁰54′E longitude at an altitude of 960m from the mean sea level. The climate is monsoonic and the average annual rainfall is 1429.79mm. Soil type is red sand stone mixed with gravel. Soil P^H ranged from 5.11 to 5.47. The mean maximum temperature ranged between 26.0 to 26.20⁰C and mean minimum temperature ranged from 12.60⁰C to 14.90⁰C.

2.2. Field Experiment

Litterbag method was followed to estimated the rate of needle litter decomposition of *Pinus kesiya* in the forest floor (Gilbert and Bocock, 1962). Litter bags of nylon net with a mesh size of 1mm and an over all size of 10cm × 10cm were used. A mesh size of 1mm was sufficient for movement of micro arthropods which are the predominant litter feeders in the forests (Sharma *et al.,* 1984). Five grams of needle leaves were kept in nylon litterbags. The litter bags were placed on the forest floor in three different zones (base, middle, top) of hill and 36 litterbags were used for each zones and a total of 108 (12 × 3 × 3) literbags were placed in each forest site and clip with nail. However care being taken so that the samples were not disturbed on the forest floor. Nine litter bags were collected from each forest sites at bimonthly intervals from the month of October 2004 to August 2006. The recovered litter bags were brought to the laboratory. The residual materials from the litter bags were washed under a fine jet of water using a 1000 *m* mesh screen to remove all the adhering soil particles and dried in hot air oven at 80⁰C to constant weight and then ground for chemical analysis. Soil temperature and soil moisture were measured using thermometer and moisture meter. Mean air temperature and rainfall was recorded from the Meteorological Department, Tulihal Airport, Imphal, Manipur (India).

2.3. Data Analysis

The decomposition constant (K) of the decomposing needle litter for the entire investigation period was calculated following exponential decay model (Olson, 1963). $e^{-kt} = DM / DMo$. Further, the time required for 50% (t_{50}) and 95% (t_{95}) decay was calculated as $t_{50} = 0.693 / K$ and $t_{95} = 3/K$ respectively. Absolute amount remaining in the needle liter after a given period of time was determined by using the following equation. Percent absolute nutrient remaining = $C/Co \times DM/DMo \times 100$ where, DMo is the original mass of dry matter, DM is the mass of dry matter after a given period, K is annual decomposition (yr^{-1}), t is the time (yr), Co is the original constant of element in needle litter and C is the concentration after a given period.

2.4. Chemical Analysis

The estimation of nitrogen and phosphorus were determined following the method given by Anderson and Ingram (1993) using Calorimeter and Potassium and sodium by Flame photometer. Lignin content of needle leaves were estimated according to Peach and Tracy (1955). Cellulose of the needle were estimated after Up-degraffs D.M. Method 1969.

3.RESULT

3.1. Litter Decomposition

The percentage of original biomass remaining of needle litter decomposition in different months in pine forest site I and site II are given in fig. 1. Higher rate of litter decomposition was recorded during rainy months from August '04 through October '04 and from June '05 through October '05 and lower rate during dry winter months. The rate of needle litter decomposition was recorded to be 53% and 49% after the completion of one year (October 2004 to August 2005) of decomposition study in forest site I and forest site II. However, at the termination of the experiment 2% and 4% of original biomass was remained in forest site I and forest site II respectively.

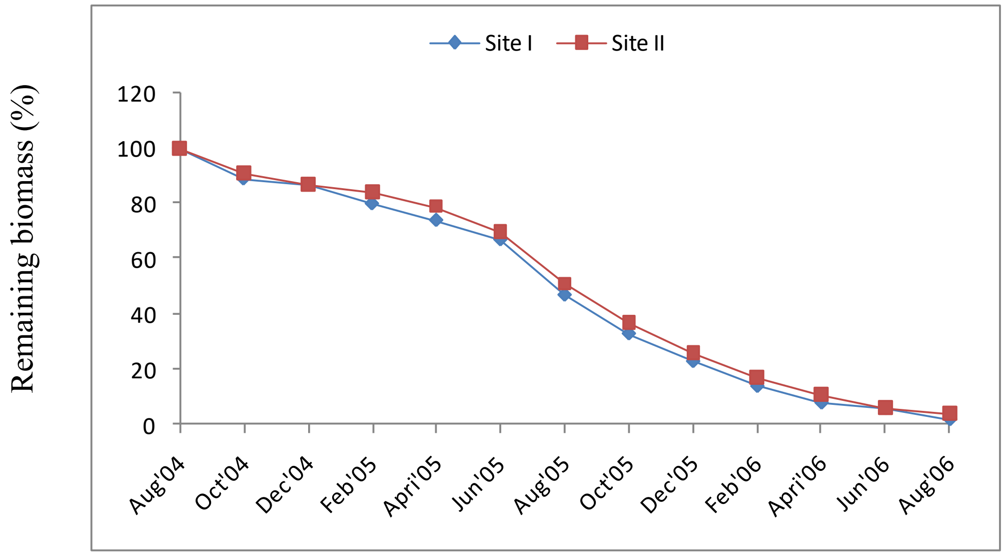

Fig. 1. Bimonthly variation of remaining biomass in the needle litter decomposition in pine forest site I and forest site II.

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3.2. Initial Litter Chemistry

The initial nitrogen, lignin, lignin to nitrogen ratio, cellulose of the initial litter material are presented in table 1.

Table 1 : Initial N, L. L to N ratio and cellulose in the pine forest site I and site II.

Forest	**IN**	IL	IL/IN	IC
Site I	0.60	27	45	20
Site II	0.59	32	54	17

IN - Initial nitrogen concentration (%), IL - Initial lignin ,
IL/IN - Initial lignin to nitrogen ratio, IC - Initial cellulose (%)

3.3. Correlations between variables

The rate of decomposition in different months was significantly correlated with the soil moisture (r = 0.51**, 0.51**); soil temperature (r = 0.55**, 0.52**) where as low correlation and significant was evident with mean air temperature (r = 0.10*, 0.16*) in forest site I and forest site II (table 2). However, rainfall showed low correlation and significant (r = 0.42*) and significant correlation (r = 0.51*) in forest site I and forest site II respectively. The variability of SM, ST, RF and MAT in forest site I and forest site II are showed in table 2.

The remaining biomass (%) showed positive correlation and significant with initial nitrogen, initial lignin, initial lignin to nitrogen ratio and initial cellulose (r = 0.78, 0.95, 0.95 & 0.87) and (r = 0.62, 0.90, 0.91 & 0.75) at the level of $P < 0.01$ in forest site I and site II respectively. The variability observed by initial nitrogen, initial lignin, initial lignin to nitrogen and initial cellulose are 61%, 90%, 90% and 76% in forest site I and 38%, 81%, 83% and 56% in forest site II.

Table 2 : Correlation between Rate of weight loss and abiotic variables in forest site I and site II (n = 12)

Parameter	**Forest Site I**		**Forest Site II**	
	R	**Variability(%)**	**R**	**Variability(%)**
Siol Moisture (SM)	0.51**	26	0.51**	26
Soil Temp.(ST)	0.55**	30	0.52**	27
Rainfall(RF)	0.42*	18	0.51*	26
Mean air Temp.(MAT)	0.10*	1	0.16*	3

* shows significant at P<0.05 level
** shows significant of P<0.01 level.

3.4. Decomposition Constant

Decomposition constant (K), as well as half time (t_{50}) and time to 95% loss of dry weight (t_{95}) are presented in table 3. The annual decomposition constant (K) was recorded to be 0.591 and 0.582 in forest site I and forest site II respectively.

Tables 3 : Rate of needle litter decomposition, turnover rate ,decomposition rate and constant (K)during litter decomposition in pine forest site I and forest site II.

Forest	**Rate of decomposition**	**Turnover rate**	**Decomposition (% per day)**	**constant (K)**
Site I	0.27	1.173	5.069	0.591
Site II	0.26	1.190	5.147	0.582

3.5. Nutrient dynamics in the decomposing needle litter

Changes in relative concentration and absolute amount or percent remaining of nitrogen, phosphorus, potassium and sodium in the residual needle litter of forest site I and site II are presented in Fig. 2. Nitrogen concentration in decomposing litter increased significantly from the original concentration (0.60%) and (0.59%) in forest site I and forest site II respectively (Fig. 2.A). However it exhibited some fluctuation followed by a rapid increased to 1.50% in forest site I and 1.17% in forest site II after 24 months elapsed.

A net immobilization of nitrogen above 100% of the initial amount was exhibited from the beginning upto December 2004 in forest site I and June 2005 in forest site II (Fig. 2.B). However nitrogen mineralization continued till the end of study and remained only 5% and 8% of original N mass in forest site I and site II respectively.

Phosphorous concentration slightly reduced then the original concentration (0.12% and 0.13%) in early stages then increased by 0.16% and 0.15% in both forest site I and site II respectively after 24 months elapsed (Fig. 2.C). There was a great released of phosphorous in the first stage of month (October2004) 26% in forest site I and 23% in forest site II (Fig. 2.D.). The pattern of P flux in both the forests sites was irregular and remained 3% and 5% after 24 months.

The concentration of potassium declined rapidly to 0.08% and 0.09% in the first month (October 2004) in both the forest sites then slowly increased by 0.20% (August, 2005) and thereafter fluctuated (Fig. 2E). Potassium was released rapidly in the initial month of October 2004 (78% and 72%) followed by slowly increased upto June 2005 but not exceed from the initial amount then released later on in both forest sites (2.F). After 24 months only 1% and 2% of K was remained in forest site I and site II respectively.

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The initial concentration of sodium in both the forest sites was 0.04% and decreasing concentration started from February 2005 (0.03%) and at the end of the assay recorded 0.02% in both forest sites (2.G). In forest site I, sodium exhibited gradual net release from the beginning till the end of assay whereas in forest site II observed an initial net release phase upto December 2004 in which 35% of Na was lost and followed by 84% of initial Na content (February'05) then release continously. Only 1% and 4% of Na was remained in forest site I and site II respectively (2.H).

4. Lignin and Cellulose Concentration During Decomposition

The lignin concentration during decomposition of needle litter increases from the original concentration (Table 1. Fig. 3 A). There is increasing trend from the initial month till the end of the study was 45% and 50% in forest site I and site II respectively. However, it was recorded some fluctuation from the month of February to June 2005 in forest sites II. Cellulose concentration in contrast, exhibited lower then the original concentration (Table 1. Fig. 3 B) in both forest sites. After 2 years of decomposition cellulose concentration was 5% and 6% in forest site I and site II respectively.

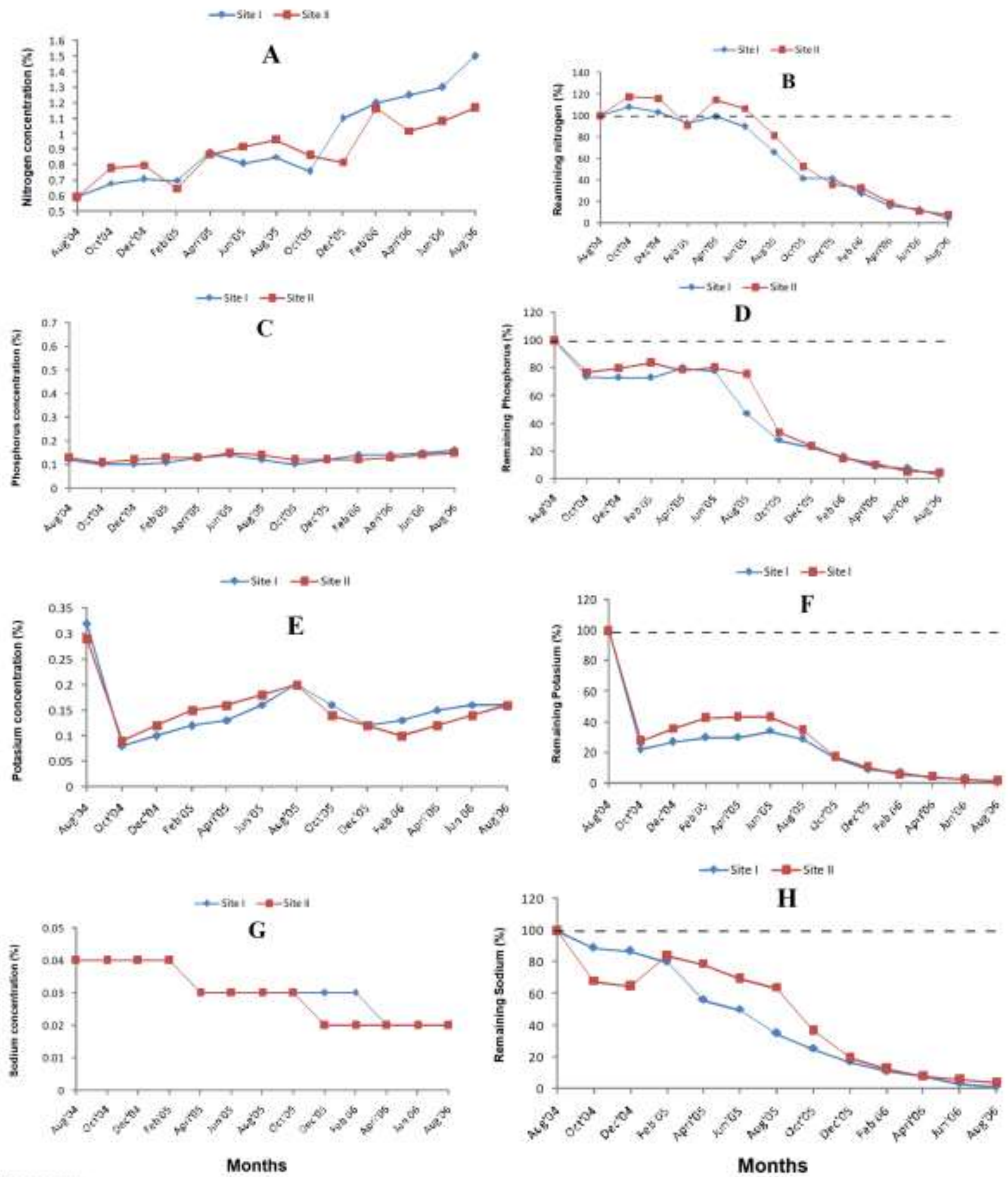

Fig. 2. Changes of N (A), P (C), K(E) and Na (G) concentration and % remaining N (B), P (D), K (F) and Na (H) in decomposing needle litter of forest site I and site II.

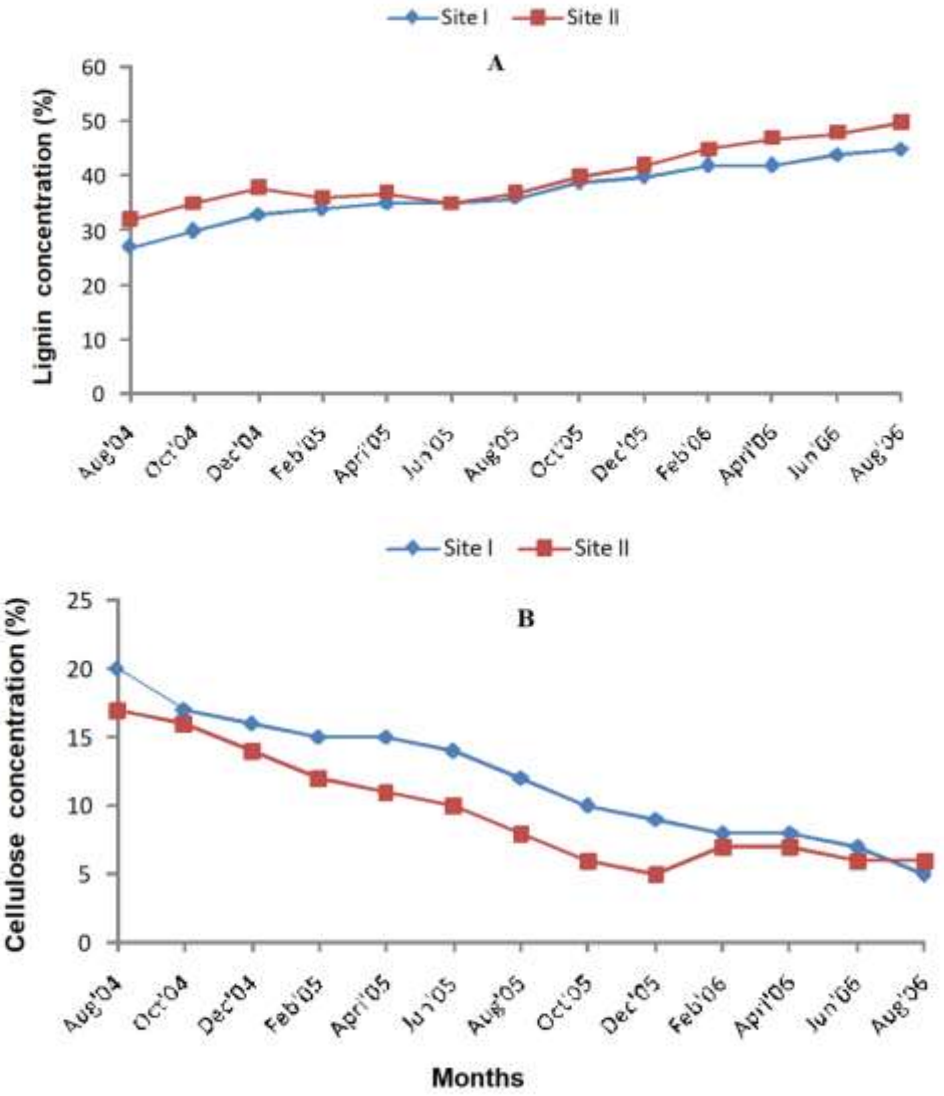

Fig. 3 Variation of lignin (3.A), celloluse (3.B) concentration in decomposing needle litter of forest site I and site II.

4.DISCUSSION

The rate of needle litter decomposition in bimonthly intervals shows different variations. The higher rate of decomposition during rainy season then in winter season in both forest sites may be due to high percentage of soil moisture and favourable soil temperature which enhances the activity of microorganisms and water soluble fractions in litter leached out more in wet summer season. Marchante et.al,2019 and Akoto et.al,2022 also reported higher rate of decomposition in rainy season and lower in winter season.

In both forest site I and site II the rate of weight loss was more during the first year (53% and 49%), then the second year (45% & 47%) and the value was comparable with the pine forest of Central Himalaya (Upadhyay and Singh, 1989), in *Casuarina equisetifolia* plantation in Orissa, India. (Misra and Nisanka, 1997) and *Populus deltoides* in Himachal Pradesh, India (Kaushal *et al.,* 2006). The total rate of needle litter decomposition of forest site I (98%) is higher than forest site II (96%) after 24 months. It may be due to the higher initial level of N, lower initial lignin, higher initial cellulose and lower initial lignin to nitrogen ratio of forest site I than forest site II (Table 1). Several workers reported that high initial level of N, low initial level of lignin, higher rate of initial cellulose and low initial lignin to nitrogen ratio resulted in the high rate of decomposition (Melillo *et al.,* 1982; Webderburn and Carter, 1999; Sarjubala, 2002; Bijayalaxmi, 2005).

In the needle litter decomposition significant positive correlation was observed with soil moisture (r=0.51**, 0.51**) and soil temperature (r=0.55**, 0.52**) than rainfall and mean air temperature in both forest site I and site II (Table 2). The maximum variability was recorded in soil temperature (30%, 27%) and soil moisture (26%). It is obvious that soil temperature and soil moisture are highly correlated with litter decomposition.

Positive and significant of remaining biomass (%) was observed with initial nitrogen, initial lignin, initial lignin to nitrogen ratio and initial cellulose (r=0.78, 0.95, 0.95 & 0.87) and (r = 0.62, 0.90; 0.91 & 0.75) at $P<0.01$ in forest site I and

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site II respectively. The variability values by initial lignin (90% and 81%), initial lignin to nitrogen (90% and 83%) shows maximum percentage than nitrogen and cellulose. It has been found that IN and IL / IN was more correlated with remaining biomass in both forest sites. David *et al.,* (1998) showed correlation of remaining mass with initial lignin and nitrogen ratio ($r = 0.74$, $P < 0.01$) in *Pinus sylvestris* in Grizedala forest, Cumbria, U.K. Upadhyay *et al.,* 1989 also reported a significant correlation of remaining biomass with lignin ($r=0.80$, $P<0.01$), lignin to nitrogen ratio ($r=0.58$, $P<0.05$) in Central Himalayan forest of India.

The rate of decomposition constant 0.59 of forest site I is little higher than forest site II (0.58). Higher rate of decomposition constant indicates the higher rate of decomposition. The present value is comparable with pine forest at Meghalaya, Shillong (0.74) by Das and Ramakrishnan, 1985; Pine forest of Europe (0.32-0.56) by Kurz *et.al.,*2005 and pine forest in U.S.A. (0.27 _ 0.54) by Cusack *et al.,* 2009 but higher than that of *Pinus densiflora* (0.21) by Namgung *et al.,* 2008 at Korea.

Nitrogen concentration in needle litter decomposition increased from the original concentration in both forest sites. Such an increased could be due to nitrogen mineralization both microbial and non microbial and deposition of nitrogen from atmosphere (Jorgenson and Myer, 1990; Kocky & Wilson, 1997). Change in the absolute amount of an element during decomposition (net immobilization or net release) is a function of both mass loss and change in residual litter. A value greater than 100% indicated immobilization of the element whereas value less than 100% indicated the release of the element from the litter.

N immobilization occurred from the beginning through December 2004 in forest site I and June 2005 in forest site II, thereafter occurred N mineralization. N immobilization in the early stages is related with increased concentration of nitrogen during decomposition in both forest sites (Fig. 2 A, B). Mun (2009) reported increased N concentration during decomposition resulted N immobilization in the early period in Oak forest, at Korea. Pankaj et.al, 2022 also reported increased N and P concentration in decomposing litter. The release of N (95%) in forest site I was found higher than forest site II (92%). It may be due to the increased of initial nitrogen concentration in forest site I (table 1). Cusack (2009) reported N release was higher in species with a high initial N concentration in pine forest at U.S.A.

Phosphorus concentration slightly reduced then the original concentration (0.12 & 0.13%) in early stages and then increased by 0.16% and 0.15% in forest site I and site II respectively after 24 months elapsed. Increased P concentration may be attributed to input throughfall and biological translocation (by fungi) from deeper soil layers (Mc Brayer and Cromark, 1980; Xu *et al.,* 2004). The rapid phosphorus loss observed in the first stage (October 2004) (Fig. 2.D) was probably a consequence of leaching of soluble P containing compounds. Many workers reported the leaching of P in the early stages of decomposition (Blair, 1988; Tripathi and Singh, 1992; Mun, 2009). The initial leaching phase was followed by some degree of P increased but did not exceed the initial amount in both the forest sites. It may be due to microbial immobilization (Bockheim *et al.,*1991).

The concentration of potassium declined rapidly from the original concentration in both forest sites. Absolute amount of K was also released rapidly in the initial months (October 2004) from the original K mass in which 78% and 72% of K was lost and then slowly releases. It can be observed that decreased rate of K concentration related with rapid release of K mass. (Fig. 2.E, F). This patter is due to the fact that potassium in being a non structural element and is subject to physical removal by leaching (Lousier and Parkinson, 1978; Tisdale *et al.,* 1993; Xu *et al.,* 2004). The concentration of Na was exhibited decreasing trend from the beginning till the end of the study in both forest sites. Sodium releases gradually upto the end of the experiment in both forest sites. Released of Na (99%) in forest site I is higher than site II (96%).

The release of nutrients in forest site I and site II was in the order K > Na > P > N. The release of nutrient elements in the order of K > P > N also reported by Hart *etal.,*1992 in *Ponderosa pine* needle litter at California.

Lignin concentration increases during decomposition preceded in both forest sites. It may be due to by an interaction of factors limiting the activity of the microbial decomposers and possibly a difference between microbial communities. The fungi and bacteria can easily degraded cellulose and hemicellulose than lignin. Lignin is a less energy rich and thus not primarily attacked and degraded more slowly. These would be a proportionally higher decomposition rate of the cellulose and the lignin concentration would increase more quickly. Berg et. al., (1993) and Pandey et. al., (2007) reported increased in lignin concentration in decomposing Scot pine needle litter and Quercus species leaf litter.

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