J. Bamboo and Rattan, Vol.7, Nos. 1&2, pp. 119-132 (2008)

Litter quality, decomposition dynamics and nutrient release in *Schizostachyum dullooa* stands in North East India

Arun Jyoti Nath and **Ashesh Kumar Das***

Department of Ecology and Environmental Science, Assam University, Silchar, 788011, Assam, India

Abstract: *Schizostachyum dullooa* is a priority bamboo species having limited distribution in forest tracts of North East India to Bangladesh, Nepal, Bhutan and Myanmar. Little is known about its ecological role in forest ecosystem. Since the analysis of litter quality, litter decomposition and the pattern of nutrient release is fundamental for understanding the soil fertility management in any ecosystem, study was carried out in the humid tropical forests at Cachar, Assam, North East India to understand the pattern of litter decomposition with the following objectives: (i) initial chemistry of leaf and sheath litter, (ii) litter mass loss and proximate carbon functions, and (iii) pattern of nutrient release from the leaf and sheath litter. Decomposition losses of leaf and sheath litter of *S. dullooa* were quantified using litterbag technique. Leaf litter had the higher concentration of N, P and K, whereas the sheath litter had higher carbon, ash free mass and cellulose. Weight loss expressed as percentage of the original dry weight, decreased exponentially with time and the equations for leaf and sheath litter may be given as $Y = 175.38\, e^{-0.3048t}$, $r = 0.9689$ and $Y = 139.55\, e^{-0.2674t}$, $r = 0.9798$ respectively. Sheath litter had the slower mass loss rate than leaf litter but characterized by higher C/N, L/N and L/P values. The pattern of N release was biphasic, and following the initial accumulation phase P concentration exhibits a decreasing trend, while release of K occurred at all the stages of decomposition. The concentration of organic compounds in leaf and sheath litter declined during the decomposition process. The ecological significance of maintenance of soil fertility through litter decomposition is also discussed.

Key words: Litter decomposition, mass loss, fertility management, *Schizostachyum dullooa*.

INTRODUCTION

Schizostachyum dullooa (Gamble) Majumdar is a major bamboo species in the successional fallows of North East India regenerating after slash and burn agriculture (Rao *et al.*, 1990). This is one of the most commercially important sympodial bamboo species growing naturally in the hilly tracts of Barak Valley (Nath *et al.*, 2007) as also in other parts of the North East India (Biswas, 1988; Hore, 1998). Moreover, the species is characterized by the restricted distribution in moist semi-evergreen forests of North East India to Sylhet in Bangladesh and in small patches in Nepal, Bhutan and Myanmar (Banik, 2000).

*To whom correspondence should be addressed: E-mail: asheshdas@sancharnet.in

Decomposition of plant litter is one of the most crucial stages in the geochemical cycling in an ecosystem (De Catanzaro and Kimmins, 1985). The quality of the plant litter assessed in terms of chemical composition such as nitrogen (N), phosphorus (P) and major cell wall compounds like lignin, cellulose and hemicellulose, affects litter decay and nutrient release (Swift *et al.*, 1979). Cellulose and lignin, the most abundant components of litter, are slowly decomposed. Isolated polymeric carbohydrates are generally decomposed more rapidly, compared to lignin (Fioretto *et al.*, 2005). A slow rate of decay results in accumulation of organic matter and nutrient stocks in soil, while a fast rate of decay helps to meet the plant uptake requirements (Isaac and Nair, 2005). Knowledge on the factors that control the rate of decay is important for prediction of decay rates for species not studied (Rogers, 2002). The present work is carried out to understand the pattern of litter decomposition with the following objectives: (i) initial chemistry of leaf and sheath litter (ii) litter mass loss and proximate carbon functions, (iii) pattern of nutrient release from the leaf and sheath litter.

MATERIALS AND METHODS

Site description

The site selected for decomposition study is a natural forest in Cachar district of Barak Valley and is situated between longitude 92°45´ East and latitude 24°41´ North. The climate of the study site is sub-tropical, warm and humid with an average rainfall of 2660 mm. The monsoon rains normally start from early June and continued to October. The mean maximum temperature ranges from 24.9°C (January) to 33.7°C

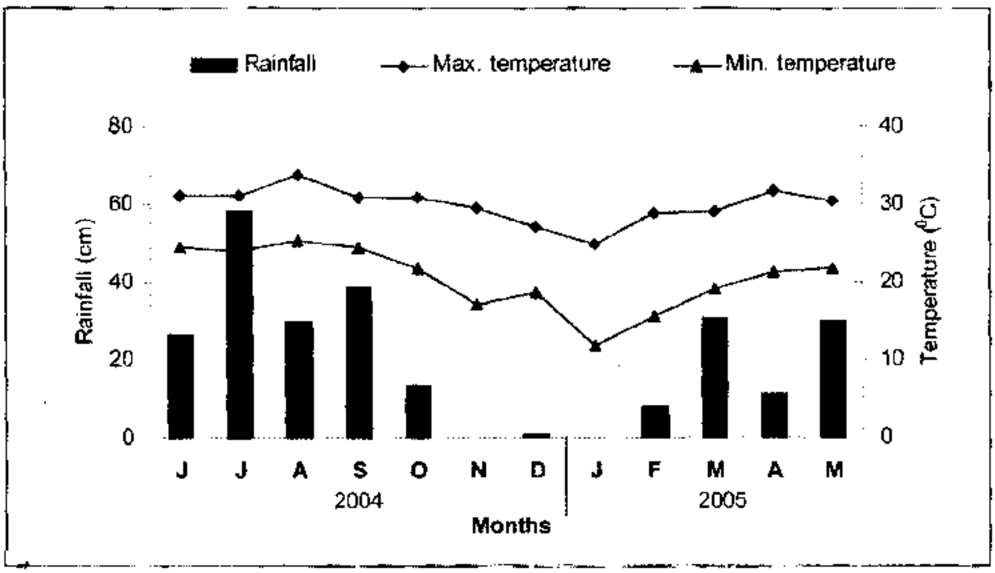

Figure 1. Weather data for the study period

(August) and the mean minimum temperature ranges from 11.8°C (January) to 24.8°C (July). The dry season usually occurs from December to February. Weather data of the study site for the study period are presented in Fig.1.

Field experiments

Decomposition of leaf and sheath litter of *S. dulloa* was studied using the nylon bag technique. Freshly abscissed leaf and sheath were collected during the peak period of litter fall (February - March) and air dried. Five gram of air dried litter samples were placed in 15 x 15 cm litterbags (1 mm^2 mesh size) and sixty such bags were prepared for leaf and sheath litter separately. Air dry to oven dry mass conversion factor was determined by oven drying separate samples at 70°C up to a constant weight. Litterbags enclosing leaf and sheath litter were placed under the closed canopy of the species on 1st June. At each sampling, five litterbags were drawn at monthly intervals from the month of June until 95 per cent of the decomposition was observed. The residual materials were separated carefully from the adhering soil particles using a small brush. The litter samples from each bag were oven dried at 70°C up to a constant weight to determine the dry weight.

Mass loss over time

Mass loss over time was computed using the negative exponential decay model (Olson, 1963):

$$X / X_0 = \exp(-kt),$$

Where, X is the weight remaining at time t, X_0 the initial weight, exp the base of natural logarithm, k the decay rate coefficient and t the time (year). The time required for 50 per cent (t_{50}) and 99 per cent (t_{99}) decay was calculated as $t_{50} = 0.693/k$ and $t_{99} = 5/k$. Monthly mass loss (g/month) from decomposing litter was determined from the difference between the mass remaining in the litterbags in each month.

Nutrient and major cell wall component analysis

Samples of initial litter chemistry and those retrieved during the sampling periods were powdered and analyzed for their chemical composition. The ash content was determined by igniting 1 g of powdered litter sample at 550°C for 6 h in a muffle furnace. A total of 50 per cent of the ash free mass was calculated as the carbon (C) content. Total nitrogen (N) was determined by a semi microkjeldahl procedure using selenium catalyst (Bremner, 1982) after digesting in sulphuric acid and hydrogen peroxide (Anderson and Ingram, 1993). Total phosphorus (P) was estimated by molybdenum blue method following triacid digestion (Perchloric acid, Nitric acid and Sulphuric acid) (Allen, 1989). Potassium was determined flame photometrically using filter for K (Allen, 1989). The total stock of C, N, P and K in litter was calculated by multiplying the concentration (%) with that of dry matter content. Per cent nutrient remaining in the litterbag was investigated as:

$$(C/C_0) \times (X / X_0) \times 100$$

where. C is the nutrient concentration in the litter samples at the time of sampling. C_0 is the nutrient concentration of the initial litter. X is the mass of dry matter at the time of sampling and X_0 is the initial dry mass of the litter sample.

Major cell wall components, *viz.*, cellulose, hemicellulose and lignin were analyzed (Peach and Tracey, 1956). For cellulose estimation 0.5 g of powdered plant sample was added with 25 per cent aqueous KOH (w/v). The mixture was then centrifuged at 3000 rpm for 15 min and filtered. The residue was then oven-dried at 105°C for 24 h and dry weight was recorded. The decant obtained during filtration for cellulose estimation was then neutralized with equal volume of glacial acetic acid and ethanol. The precipitate was filtered and then oven dried at 105°C and the weight was recorded which gave the hemicellulose content. For lignin estimation 0.5 g of powdered plant sample was mixed with 20 ml of 72 per cent H_2SO_4 and kept in deep freeze for 24 h. This is followed by centrifugation at 3000 rpm for 15 min. Residue was collected and washed to remove traces of H_2SO_4 and then oven dried and the weight was recorded. The amount weighed is the total lignin content.

Statistical analysis

Statistical differences between the mass loss of residual litter of leaf and sheath were examined through analysis of variance (ANOVA). Correlation analysis was performed using the statistical software STATISTICA, version 6.0.

RESULTS

Initial chemistry of leaf and sheath litter

Initial chemistry of leaf and sheath litter varied considerably (Table 1). Leaf litter had the higher concentration of N, P and K, whereas the sheath litter had higher concentration of carbon, ash free mass and cellulose. The C/N, L/N and L/P values were higher in sheath than leaf litter.

Litter mass loss and carbon functions

Leaf and sheath litter mass loss during decomposition is depicted in Fig. 2. Total mass loss increased with progress of time but the monthly mass loss was not uniform. Comparatively higher mass loss occurred during the period of June to November in leaf litter and June to October in sheath litter. The mean monthly leaf litter loss was 0.43 g with the highest amount during June (0.96 g) in comparison to sheath litter,

Table 1. Initial litter chemistry of leaf and sheath litter of *S. dullooa*

Parameters	Litter type	
	Leaf	Sheath
Carbon (%)	32.5	41.4
Nitrogen (%)	0.76	0.58
Phosphorus (%)	0.11	0.07
Potassium (%)	0.37	0.22
Ash free mass (%)	74.5	96.3
Lignin (%)	30.68	32.34
Cellulose (%)	35.28	36.11
Hemicellulose (%)	5.98	7.13
C/N	42.76	71.37
C/P	295.45	591.43
Lignin/N	40.37	55.76
Lignin/P	278.91	462.0
Lignin/Cellulose	0.87	0.90

where the mean monthly loss was 0. 408 g with peak during October (1.08 g). ANOVA exhibited statistically different pattern of mass loss in residual leaf and sheath litter ($P<0.05$). Weight loss expressed as a percentage of the original dry weight, decreased exponentially with time (Fig. 3). The equations for leaf and sheath litter mass loss may be given as $Y = 175.38\ e^{-0.3048x}$, $r = 0.9689$ and $Y = 139.55\ e^{-0.2674x}$, $r = 0.9798$ respectively; where Y = percent leaf/ sheath litter loss in weight, x = decomposition time and e = base of the natural logarithm. Annual decay constant, half life ($t_{0.50}$) and

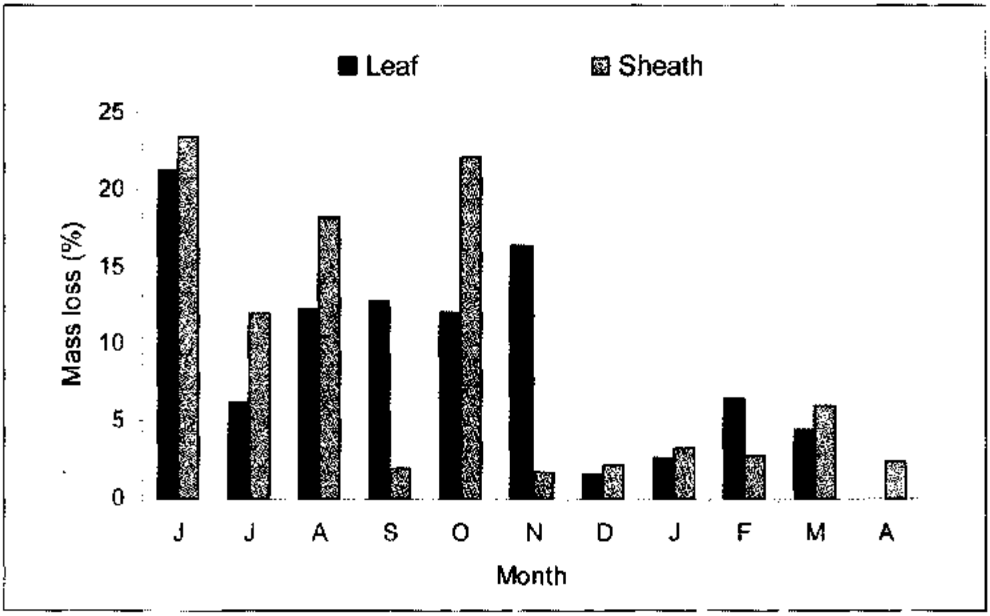

Figure 2. Pattern of mass loss during decomposition of leaf and sheath litters of *S. dullooa*.

Table 2. Annual decay constant for leaf and sheath litter of *S. dullooa*

Litter type	Decomposition rate constant K (year^{-1})	Time required for 50 per cent decomposition(days)	Time required for 99 per cent decomposition (days)
Leaf	1.73	146	1056
Sheath	1.52	167	1204

time for 99 per cent loss of dry weight ($t_{0.99}$) of leaf and sheath litter are presented in Table 2.

The decay rate of leaf litter was significantly related with lignin ($r = 0.463$, $P<0.05$), hemicellulose ($r = 0.479$, $P<0.05$) and lignin/cellulose ($r = 0.406$, $P<0.05$) content;

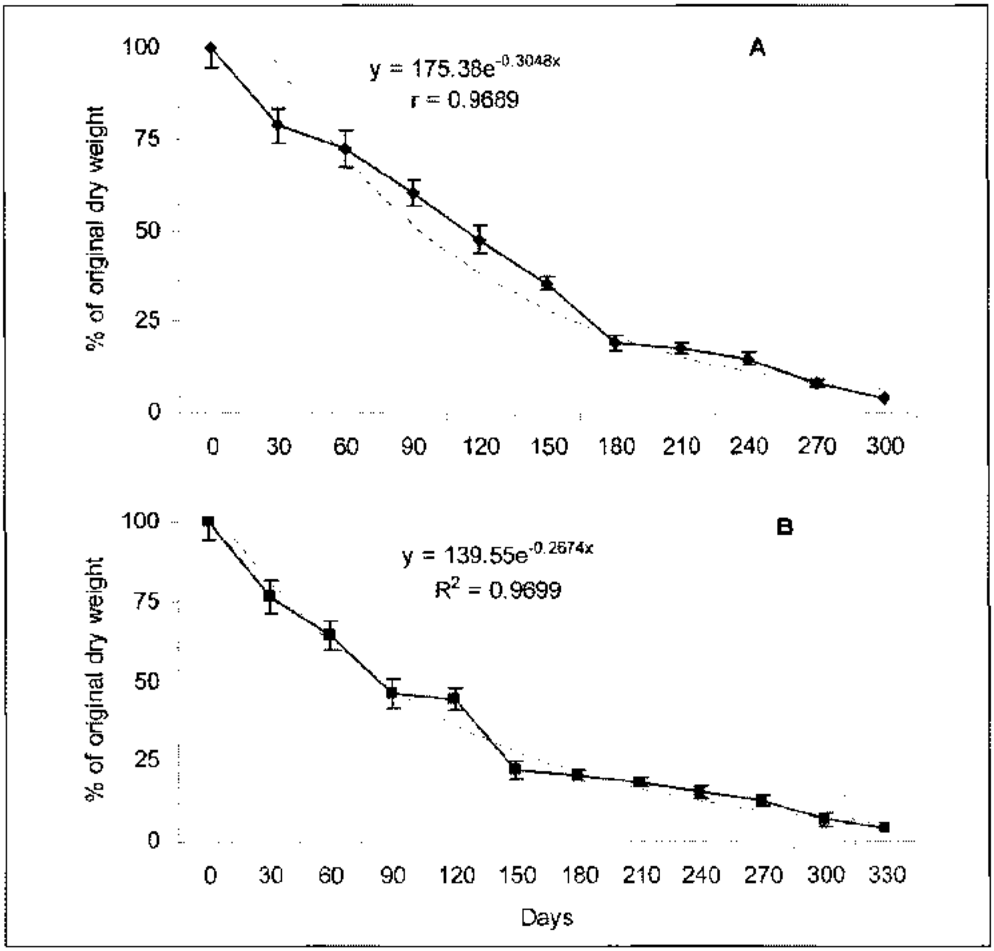

Figure 3. A. Leaf and B. Sheath litter decomposition of *S. dullooa*. Solid line denotes cumulative weight loss, while broken line denotes predicted weight loss based on exponential model.

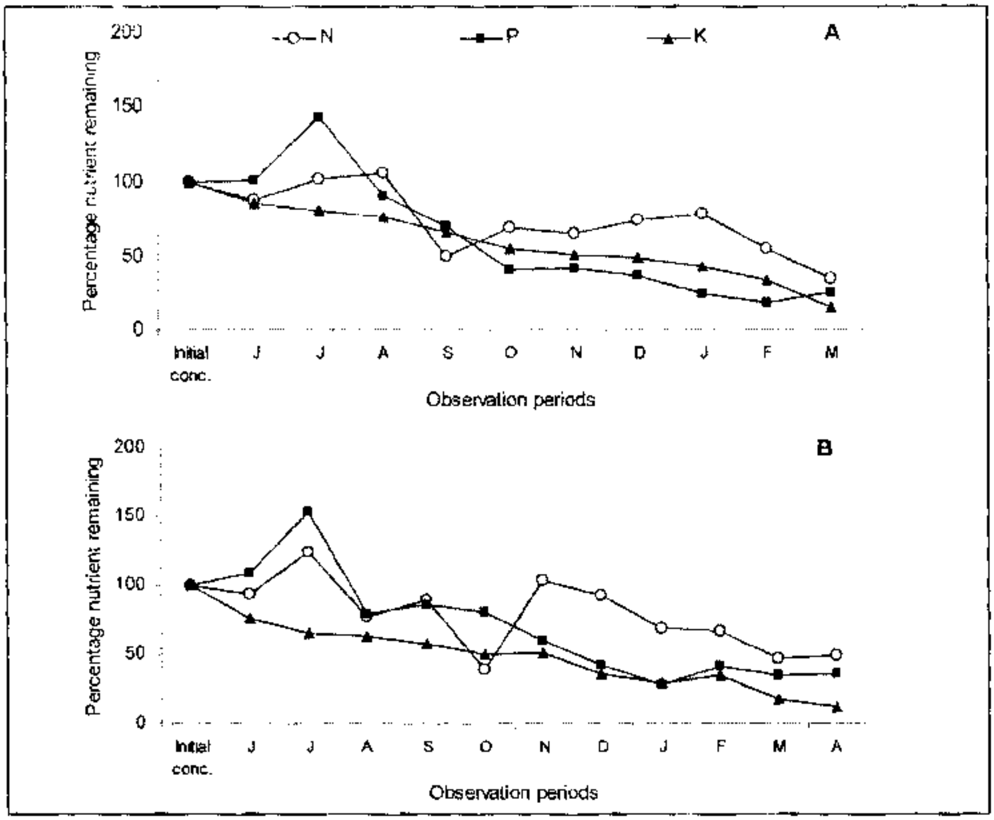

Figure 4. Nutrient remaining in the decomposing leaf (A) and sheath (B) litter of *S. dullooa.*

while sheath litter was significantly related with phosphorus (r = 0.252, P<0.05), lignin (r = 0.487, P<0.001), hemicellulose (r = 0.489, P<0.001) and lignin/cellulose (r = 0.442, P<0.001). Rainfall and aerial temperature were insignificantly correlated with the decay rate of leaf and sheath litter.

Ash content in the leaf and sheath litter gradually increased with time. The rate of increase in ash content as a function of time was rapid for the month of June to September in leaf litter and June to October in sheath litter. When expressed as ash free dry mass, loss of leaf and sheath litters after 10 and 11 months respectively was 85 and 60 per cent.

Pattern of nutrient release from the leaf and sheath litters

A complex dynamics of N release was observed. The pattern of N release was biphasic. An accumulation phase of N in leaf and sheath litters was recognized from June to August. A similar rise in the concentration was observed during December to January. At the end of the study period, the concentration of N remained in the decomposing litter was 34.79 and 49.42 per cent in leaf and sheath litters respectively of its original

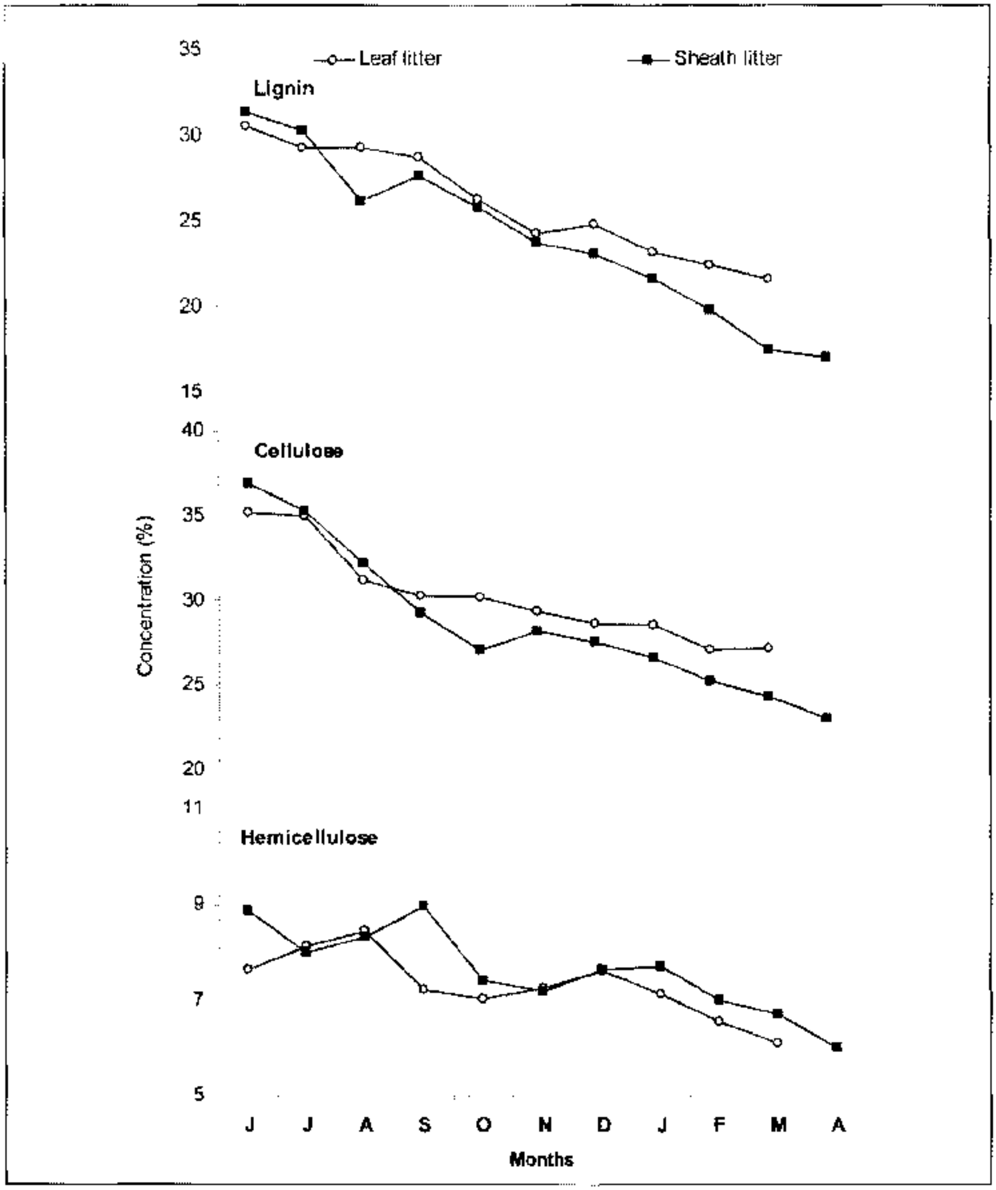

Figure 5. Concentration (%) of organic compounds (lignin, cellulose and hemicellulose) during the leaf and sheath litter decay of *S. dullooa.*

content. P concentration in leaf and sheath litter exhibited an increasing trend from June to August and thereafter declined sharply suggesting immobilization was greater during the initial phase of decomposition (Fig. 4). The percentage of P concentration in the remaining mass of decomposing leaf and sheath litters was 25.53 and 35.84 per cent respectively of its original content. The increase in P concentration from the original amount was recorded up to 43 and 52 per cent for leaf and sheath litters respectively. The pattern of release of K from the decomposing mass revealed the loss of K occurred at all the stages of decomposition.

Degradation of organic compounds

The initial concentration of organic compounds (lignin, cellulose and hemicellulose) among leaf and sheath litters does not differ significantly but their degradation pattern during the decay process differed significantly ($P<0.05$). The concentration of lignin, cellulose and hemicellulose declined during the decomposition process (Fig. 5). The lignin, cellulose and hemicellulose concentrations of the leaf and sheath litters after 90 per cent decomposition were 21.67 per cent, 17.43 per cent, 27.13 per cent; 23 per cent, 6.11 per cent and 6 per cent respectively.

DISCUSSION

Initial chemistry of litter mass revealed leaf litter contained greater amount of NPK than sheath litter. The concentration of lignin was high in sheath litter than leaf litter. Initial lignin concentration in leaf litter was lower than that reported for *Dendrocalamus hamiltonii* in the three jhum fallows in North East India (Deka and Mishra, 1982), but higher than *Bambusa tulda* growing in the Eastern Himalaya (Deb *et al.*, 2005). Lignin is considered the primary variable in determining the decay rates of litter, which is resistant to decay as well as slows down the decay of other cell constituents (Chesson, 1997). The leaf and sheath litters in the present study had greater initial C/N ratio (42.76 and 71.38 respectively). Fioretto *et al.* (2003) suggested rate of retranslocation of nutrients from senescent leaves to the plant body prior to abscission corresponds to variation in C/N ratio. Myers *et al.* (1994) reported that the substrate with C/N < 25 are of high quality and release mineral N at a faster rate compared to low quality residues (C/N >25).

The litter mass loss increased continuously as the time elapsed. A highly negative correlation was established between time elapsed and per cent weight remaining in the decomposing litter. Litter mass loss showed a rapid phase of initial mass loss in which 65 per cent of the leaf litter and 78 per cent of the sheath litter weight loss occurred during the first 150 days (rainy season of the year). This season is also characterized by warm and humid conditions. Lavelle *et al.* (1993) had opined that litter decomposition in the warm and humid condition is more rapid as the prevailing environmental conditions are conducive for rapid decay. The mean monthly rate of dry weight loss during the period was 0.578 g for leaf litter and 0.728 g for sheath litter. This trend may be due to higher initial water-soluble materials and break down of the litter by decomposers, especially micro flora.

The time required for the decomposition is directly related to the decomposition rate constant (k). The rate of decomposition of litter is strongly influenced by the environment (temperature and moisture) and resource quality (lignin, nitrogen, condensed and soluble polyphenol concentration) (Swift *et al.*, 1979; Sariyildiz *et al.*, 2005). In the present study resource quality (lignin, nitrogen, phosphorus) was assumed to be significantly related to the decomposition rate than environmental factors. Greater decomposition rate in leaf than sheath litter can be attributed to the structural chemistry of higher N, P and lower C/N, L/N and L/P ratio in leaf litter. Differences in the decomposition rate of leaf and sheath litter can also be attributed to the differences in the surface toughness as the sheath litters has the tough surface than former. Rogers (2002) reported physical toughness can affect the rate of decomposition.

Increase in ash content in the samples over the sampling periods is more likely due to addition of mineral material to the litterbags either through dry deposition or as a result of contamination from the adjacent mineral soil by different organisms' activity. Earthworm casts, insect frass, products of microbial growth such as fungal hyphae and fragmented pieces of surrounding litter are all potential sources of organic contamination (Idol *et al.*, 2002). Rapid rate of increase in ash content during the period of June to October coincides with the peak rainfall season of the year, suggesting the greater organic contamination through surface runoff. Mass loss when expressed as ash free dry mass, leaf litter exhibited greater loss (85%) than sheath litter (60%). Such differences can be attributed to the variability in litter material and organic contamination.

Pattern of nutrient release and degradation of organic compounds

The N concentration decreased about 13 per cent and 6 per cent in leaf and sheath litters respectively during the initial stage of decomposition process followed by an accumulation phase. The percentage increase in N concentration in the remaining mass of decomposing leaf and sheath litters was 6 per cent and 24 per cent respectively of its original content. The rate of decrease of N in the initial stage of decomposition is due to the loss of soluble and easily decomposable compounds, through either leaching or assimilation and catabolism by decomposer population (Wieder and Lange, 1982). Accumulation phase of N in the decomposing process is comparable with the studies of Maoyi *et al.* (1991) and Qungen *et al.* (2002) in *Phyllostachys pubescens*; Sujatha *et al.* (2003) in *Ochlandra travancorica* and Deb *et al.* (2005) in *Bambusa tulda* and *Dendrocalamus hamiltonii*. Such accumulation is almost certainly due to the intense immobilization activity of microbes (Bocock, 1963; Garkoti and Singh, 1999), nutrient input from throughfall (Bocock, 1963) and atmospheric precipitation (Das and Ramakrishnan, 1985). In the present investigation N content in both leaf and sheath litters is less than 1 per cent and according to Seneviratne (2000), N values less than 2 per cent are considered to be associated with net immobilization, due to scavenging of N by microbes. Following the initial accumulation phase, P concentration exhibits a decreasing trend. However, Singh *et al.* (1999) reported a consistent increase in P concentration throughout the study period. Furthermore, Deb *et al.* (2005) reported almost decreasing trend of P release in leaf litters of *B. tulda* and *D. hamiltonii*. Such differences in the P mineralization and immobilization can be attributed to the differences in the decomposer communities prevailing under different climatic conditions. P being a structural element, changes during decay are highly dependent on the heterotrophic microorganisms in soil (Isaac and Nair, 2005). The pattern of release of K at all the stages of decomposition in the present study can be due to its non- structural nature (Tisdale *et al.*, 1993) that made it liable to the leaching losses (Isaac and Nair, 2005) throughout the litter decay process. The pattern of mobility of elements in both leaf and sheath litters was K>P>N and this pattern is comparable with *D. hamiltonii*, a dominant bamboo species in the early successional vegetation after slash and burn agriculture in North East India (Toky and Ramakrishnan, 1984). However, Sujatha *et al.* (2005) reported nutrient mobility from decomposing reed bamboo leaf litter in the order K>N>P.

The lignin content (30.68 and 32.34 %) in the leaf and sheath litters of the present study is higher than that reported in other bamboo species studied in North East India (Arunachalam *et al.*, 2005; Deb *et al.*, 2005). Organic components have the characteristics to slow the decomposition process, although polymeric carbohydrates are generally decomposed more rapidly, compared to lignin (Fioretto *et al.*, 2005). Cellulose components exhibited greater rate of decay than lignin and hemicellulose. The microbes easily attack cellulose after the soluble fractions have been depleted (Swift *et al.*, 1979). Nevertheless, lignin physically protects most of the cellulose and hemicellulose from enzymatic hydrolysis; neither group of compounds decomposes independently (Cooke and Whipps, 1993). Osono and Takeda (2004) reported litter types with initial L/N ratios higher than 23-25 or with an initial L/P ratio higher than 500-620, contained initially excess lignin compared to N and P and had the potential to immobilize N and P until the L/N and L/P ratio reached critical values. In the present study for leaf and sheath litter, the initial L/N ratio was higher and L/P ratio was lower than the reported value. However, in comparison to leaf litter (40 and 279 respectively) initial L/N and L/P ratio of sheath litter (56 and 462 respectively) was much higher. Therefore, slower decomposition of sheath than leaf litter can also be attributed to higher L/N and L/P concentration in the former. Aber *et al.*, 1990 reported that the L/N ratio exerts a strong influence on organic matter decomposition rates, because N reacts with lignin and forms recalcitrant products that are highly resistant to degradation.

Rate of litter decomposition and pattern of nutrient release in leaf and sheath litters exhibited relatively slower decomposition rate and greater nutrient retention in the litter mass. The greater retention of nutrients in the litter itself is helpful in their retention in the soil system against losses through run-off (Toky and Ramakrishnan, 1981). Further, slower decomposition rate could somewhat decrease the organic matter turnover rate in the forest floor (Bo *et al.*, 2006). As a result, fertility of the soil is maintained that in turn ensures adequate utilization by the plant. Therefore, the success of the species in the prevailing environmental condition is characterized by its nutrient conservation strategy (Rao and Ramakrishnan, 1989) and soil fertility maintenance.

ACKNOWLEDGEMENT

This work was supported by the G.B. Pant Institute of Himalayan Environment and Development, Almora in the form of a research project.

REFERENCES

Aber, J.D., Mellilo, J.M. and Mc Claugherty, C.A. 1990. Predicting long term patterns of mass loss, nitrogen dynamics and soil organic matter formation from fine litter chemistry in temperate forest ecosystems. *Can.J.Bot.* 68: 2201-2219.

Allen, S.E. (Ed.) 1989. Chemical Analysis of Ecological Materials. Blackwell Scientific Publications, Oxford.

Anderson, J.M. and Ingram, J.S.I. 1993. Tropical Soil Biology and Fertility. Handbook of Methodology, CAB International, Wallingford, UK.

Arunachalam, K., Upadhyaya, K. and Arunachalam, A. 2005. Foliage decomposition and nutrient release dynamics of *Bambusa balcooa* and *Bambusa pallida* in a 9-year-old jhum fallow. *J. Bamboo and Rattan* 4(1): 41-54.

Banik, R.L. 2000. Silviculture and Field - Guide to Priority Bamboos of Bangladesh and South Asia. Government of the People's Republic of Bangladesh, Bangladesh Forest Research Institute, Chittagong.

Biswas, S. 1988. Studies on bamboo distribution in north-eastern region of India. *Indian Forester* 114(9): 514-531.

Bo, L., Qing, L., Yan, Wu. and Hai, H.E. 2006. Nutrient and litter patterns in three subalpine coniferous forests of Western Sichuan, China. *Pedosphere* 16(3): 380-389.

Bocock, K.L. 1963. Changes in the amount of nitrogen in decomposing leaf litter of sessile oak (*Quercus pertaca*). *J. Ecol.* 51: 555-566.

Bremner, J.M. 1982. Inorganic nitrogen. In: A.L. Page, R.H. Miller and D.R. Keeney (Eds.). Methods of Soil Analysis. Part 2, American Society of Agronomy, Madison.

Chesson, A. 1997. Plant degradation by ruminants parallels with litter decomposition in soils. In: G. Cadisch and G.E.Giller (Eds.). Driven by Nature: Plant Litter Quality and Decomposition. CAB International, Wallingford, UK: 47-66.

Cooke, R.C. and Whipps, J.M. 1993. Ecophysiology of Fungi. Blackwell, Oxford, UK.

Das, A.K. and Ramakrishnan, P.S. 1985. Litter dynamics in Khasi pine (*Pinus kesiya* Royle Ex. Gordon) of North Eastern India. *Forest Ecol. Manage.* 10: 135-153.

De Catanzaro, J.B. and Kimmins, J. P. 1985. Changes in weight and nutrient composition of leaf litter in three forest ecosystem types on coastal British Columbia. *Can. J. Bot.* 63: 1046-1056.

Deb, S., Arunachalam, A. and Arunachalam, K. 2005. Cell-wall degradation and nutrient release pattern in decomposing leaf litters of (*Bambusa tulda* Roxb.and *Dendrocalamus hamiltonii* Nees.) in a bamboo based agroforestry system in North East India. *J. Bamboo and Rattan* 4(3): 257-277.

Deka, H.K. and Mishra, R.R. 1982. Decomposition of bamboo (*Dendrocalamus hamiltonii* Nees.) leaf litter in relation to age of Jhum fallows in North East India. *Plant and Soil* 68: 131-139.

Fioretto, A., Nardo, C.D., Papa, S. and Fuggi, A. 2005. Lignin and cellulose degradation and nitrogen dynamics during decomposition of three leaf litter species in a Mediterranean ecosystem. *Soil. Biol. Biochem.* 37: 1083-1091.

Fioretto, A., Papa, S. and Fuggi, A. 2003. Litter-fall and litter decomposition in a low Mediterranean shrubland. *Biol. Fert. Soils* 39: 37-44.

Garkoti, S.C. and Singh, S.P. 1999. Litter decomposition and nutrient release in Central Himalayan high altitude forests. *Trop. Ecol.* 40(1): 19-26.

Hore, D.K. 1998. Genetic resources among bamboos of Northeastern India. *J. Econ. Tax. Bot.* 22(1): 173-181.

Idol, T.W., Holzbaur, K.A., Pope, P.E. and Ponder, F. 2002. Control-bag correction for forest floor litterbag contamination. *Soil Sc. Soc. Amer. J.* 66: 620-623.

Issac, S.R. and Nair, M.A. 2005. Biodegradation of leaf litter in the warm humid tropics of Kerala, India. *Soil. Biol. Biochem.* 37: 1656-1664.

Lavelle, P., Blanchart, E., Martin, A., Martin, S., Spain, A.A., Toutain, F., Barois, Schaefer and Roger, L. 1993. A hierarchal model for decomposition in terrestrial systems: application to soils of humid tropics. *Biotropica* 25(2): 130-135.

Nath, A.J., Das, G and Das, A.K. 2007. Culm characteristics and population structure of dolu bamboo (*Schizostachyum dullooa* (Gamble) Majumder) in Barak Valley, Northeast India: the need for conservation and implication for management. *J. Amer. Bam. Soc.* 20: 15-20.

Maoyi, F., Qungen, C., Mingyu, F. and Singsong, X. 1991. Nutrient cycling in bamboo stands: nutrient input and its loss through runoff in watersheds in pure *Phyllostachys pubescens* stands. In: Bamboo in Asia and the Pacific. Proceedings of the Fourth International Bamboo Workshop held in Chiangmai, Thailand. FORSPA Publication, 6.

Myers, R.J.K., Palm, C.A., Cuevas, E., Gunatilleke, I.U.N. and Brossard, M. 1994. The synchronization of nutrient mineralization and plant demand. In: P.L. Woomer and M.J. Swift (Eds.). The Biological Management of Tropical Soil Fertility. John Wiley and Sons, UK: 81-116.

Olson, J.A. 1963. Energy storage and the balance of producers and decomposers in ecological system. *Ecology* 44: 322-331.

Osono, T. and Takeda, H. 2004. Accumulation and release of nitrogen and phosphorus in relation to lignin decomposition in leaf litter of 14 tree species in a cool temperate forest. *Ecol. Res.* 19: 593-602.

Peach, K. and Tracey, M.V. 1956. Modern Methods of Plant Analysis. Volume 1, Springer, Berlin.

Qungen, C., Maoyi, F. and Zhengcai, L. 2002. Pattern of mass loss and nutrient accumulation and release in leaf litter in *Phyllostachys pubescens* (moso bamboo) stands. In: A. Kumar, I.V.R. Rao, and C.B. Sastry (Eds.). Bamboo for Sustainable Development, VSP and INBAR.

Rao, K.S. and Ramakrishnan, P.S. 1989. Role of bamboos in nutrient conservation during secondary succession following slash and burn agriculture (jhum) in North East India. *J. Appl. Ecol.* 26: 625-633.

Rao, K.S., Ramakrishnan, P.S. and Saxena, K.G. 1990. Architectural plasticity of bamboos and its significance in the succession. *Bamboo Journal* 8: 92-99.

Rogers, M.H. 2002. Litterfall, decomposition and nutrient release in a lowland tropical rain forest, Morobe Province, Papua New Guinea. *J. Trop. Ecol.* 18: 449-456.

Sariyildiz, T., Anderson, J.M. and Kucuk, M. 2005. Effects of tree species and topography on soil chemistry, litter quality, and decomposition in North East Turkey. *Soil. Biol.Biochem.* 37: 1695-1706.

Seneviratne, G. 2000. Litter nitrogen release in tropical agroecosystems. *Curr. Sci.* 79(8): 1054.

Singh, K.P., Singh, P.K. and Tripathi, S.K. 1999. Litter fall, litter decomposition and nutrient release in four native tree species raised on coal mine spoil at Singrauli, India. *Biol. Fert. Soils.* 29: 371-378.

Sujatha, M.P., Jose, A.I. and Sankar, S. 2003. Leaf litter decomposition and nutrient release in reed bamboo (*Ochlandra travancorica*). *J. Bamboo and Rattan* 2(1): 65-78.

Swift, M.J., Heal, O.W. and Anderson, J.M. 1979. Decomposition in Terrestrial Ecosystems. Blackwell Science, Oxford.

Tisdale, S.L., Nelson, W.L., Beaton, J.D. and Havlin, J.L. 1993. Soil Fertility and Fertilizers. Fifth edition, Prentice Hall of India Private Limited, New Delhi: 53-60.

Toky, O.P. and Ramakrishnan, P.S. 1981. Runoff and infiltration losses related to shifting agriculture (jhum) in North-Eastern India. *Environ. Conserv.* 8:313-321.

Toky, O.P. and Ramakrishnan, P.S. 1984. Litter decomposition related to secondary succession and species type under slash and burn agriculture (jhum) in North-Eastern India. *Proceedings of Indian National Science Academy* 50(1): 57-65.

Wieder, R.K. and Lange, G.E. 1982. A critique of the analytical methods used in examining decomposition data obtained from litter bags. *Ecology* 63: 1636-1642.