Eco. Env. & Cons. 28 (May Suppl. Issue) : 2022; pp. (S535-S543)
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ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2022.v28i03s.078

Potential of nutrient input and released from decomposing leaf litter of three dominant tree species found in a subtropical semi evergreen riparian forest of Dikhu river, Nagaland, India

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(Received 11 January, 2022; Accepted 20 February, 2022)

ABSTRACT

Studies on nutrient dynamic in riparian ecosystem is very less compared with the upland forest ecosystem. The main aim of the study was to compare the rate of nutrient input and release through decomposition from leaf litterfall of three dominant tree species, i.e., *Melia azedarach* L., *Terminalia chebula* Retz. and *Duabanga grandiflora* (DC.) Walp. found in a subtropical semi evergreen riparian forest of Dikhu river, Nagaland, India. The concentration of the initial composition of plant nutrients *viz*., C, N, P and K was analysed from the grounded air-dried leaf litter and nutrient released through decomposition from the leaf litter was estimated by using litter trap approach following standard methods. The initial concentration of nutrients in all the 3 leaf species followed the trend as (1.12%) N > (0.21%) K > (0.098%) P in *M. azedarach*, (1.40%) N > (0.17%) K > (0.086%) P in *T. chebula* and (1.98%) N > (0.22%) K > (0.074%) P in *D. grandiflora*. Carbon content was highest in the entire 3 leaf litter component and followed the pattern as *D. grandiflora* (65.50%) >*T. chebula* (60.50%)>*M. azedarach* (51.80%). In *M. azedarach* and *D. grandiflora*, N is accumulated during the initial phase of decomposition and released in the later phase. However, in *T. chebula*, N is released in the initial phase and immobilization in the later phase. In all the 3 species, the released of C follows a similar pattern by characterizing early immobilization in the first 9 months (0 to 243 days). A rapid rate of P released was observed at the early decomposition period. There observed a faster decrease of K (%) from all the decomposing leaf litter. In conclusion, it was found that differences in chemical composition and nutrients release dynamics during decomposition of leaf litter was observed in all the 3 tree species.

Key words : *Riparian forest, Leaf litter decomposition, Nitrogen immobilization, Initial chemical composition, Nutrient dynamic*

Introduction

Litterfall is a critical pathway for nutrient transfer in riparian zones. The temporal dynamics of litter inputs (litterfall phenology) also plays an important role in ecosystem functioning because they determine the temporal variation in the supply of organic matter and light availability to aquatic systems (Acuna *et al*., 2007; Gregory *et al*., 1991). Tree species composition and the hydrologic regime of rivers are the main factors that contribute to explain litter quantity, quality, and phenology in floodplain forests. Both forest composition and hydrology have been altered in most rivers during recent decades. This alteration is not expected to be reverted in the near future but instead is expected to be aggravated by increasing global pressure on the natural water resources (Tockner *et al*., 2003). The important of litterfall decomposition, as a stage of matter and energy balance in nature and some modified ecosystem, is confirmed by the results of many studies. In forest ecosystems, decomposition is a critical process in nutrient cycling, which often determined their bioavailability. Chemical composition of initial material, soil properties, including biological activity, species composition of plant communities and climatic conditions (especially temperature and humidity) are the most important factors affecting intensity of the process Drewnik *et al*. 2006 and Preston *et al*. (2009). Quantitative proportions between the annual production of litterfall and its decomposition rate in a long time determine forms and stocks of soil organic matter. Tree species associated with riparian areas (like alder, popular and willow) produce rich in nutrients, soft, susceptible to decomposition litterfall, which is almost completely decomposed within the first year Jonczak, 2009. Forest productivity depends on efficient nutrient cycling mechanisms that ensure the rapid turnover of litter (Vendrami *et al*. 2012). Foliar litter occupies a major fraction of the litter in forest ecosystems and maybe totally decomposed within a year in subtropical and tropical areas Meentemeyer 1984. Many studies on litterfall production, decomposition, and nutrient released by trees in the upland forest have been carried out in different parts of the world. Few works have been carried on litterfall, decomposition, and nutrient released in riparian forest elsewhere, (Gonzalez 2012); Jonczak *et al*. 2015; Londe *et al*. 2016; Tonin *et al*. 2017. Many have studied litterfall dynamics in the tropical terrestrial forest but studies concerning about the nutrients dynamics of riparian forest are very rare. Till date, no literatures are available about the study of nutrient dynamics from riparian forest found in India. The forest is dominated by three tree species *viz*., *Melia azedarach*, *Terminalia chebula*and *Duabanga grandiflora* found along the upper, middle and lower zones of Dikhu river, Nagaland, India (Devlin *et al*., 2018). Hence, the present study has been taken up to evaluate the nutrients inputs and released from leaf litter of these three dominant tree species found along the Dikhu river.

Materials and Methods

Experimental set up for the study of released nutrients during leaf litter decomposition of 3 dominant tree species

Leaves of three dominant tree species viz., *Melia azedarach* L., *Terminalia chebula* Retz. and *Duabanga grandiflora* (DC.) Walp. were collected from Zone I, Zone II and Zone III located at upper, middle and lower stretch of the river. The collected leaves were brought to the laboratory and air dried. Nylon litter bags of 20 x 20 m size with 1 mm mesh were used to quantify decomposition rates. 50 grams of air-dried leaf samples of each species were kept separately in each litter bag. A mesh size of 1 mm was sufficient to permit movement of micro arthropods which are the predominant litter feeders (Singh *et al)*., 1990. During March, 2016, 120 litter bags of each species were placed separately in the forest in such a manner that they were in contact with soil and care was taken not to disturb the floor vegetation as much as possible. Five litter bags of each species were recovered randomly at monthly interval between April, 2016 and March, 2017. Immediately after recovery, the litter bags were placed individually in the polyethylene bags and transported to the laboratory. The recovered residual material was carefully washed with distilled water to remove soil particles then oven dried at 60 ^{0}C to constant weight. The samples were grounded separately and analyzed for the organic carbon, total nitrogen, total phosphorus and total potassium following the same methods used in the estimation of initial nutrients concentration. From the data obtained, the following parameters were calculated using the equations as given below:

1. Nutrients remaining in the residual litter Bockhelm *et al*. 1991

$$\text{Nutrient (\%) remaining} = \frac{C}{Co} \times \frac{DM}{DMo} \times 100$$

where, C = The conc. of the nutrients at time 't'

C_o = Initial conc. of the nutrient

DM = Dry wt. of the litter after time't'. (i.e., after decomposition)

DM_o = Initial dry wt. of the litter

2. Monthly release pattern of nutrients (N, P, K, C) from the leaf litter

=Nutrients in initial next month – Nutrients air-dried leaf

Annual litterfall (t ha $a^{-1}a^{-1}$)

Thus, Net release annual residual = Summing up all the nutrients during the entire period.

4. Nutrients return or input (Kg^{-1} ha^{-1} year^{-1})= Nutrient concentration (mg g^{-1}) x Total annual litterfall

(Kg^{-1} ha^{-1} $year^{-1}$)

Estimation of initial chemical composition leaf litter of 3 dominant tree species

Composite samples of freshly fallen leaves of three dominant tree species *viz*., *Melia azedarach* L., *Terminalia chebula* Retz. and *Duabanga grandiflora* (DC.) Walp. found to be dominant at upper zone, middle zone and lower zone of the river respectively were collected from the forest floor of the riparian forest at each plot. The collected leaves were brought to the laboratory and air-dried for one week in the laboratory. Samples of each air-dried leaf litter were grounded by using a Wiley mill and sieved through 1 mm mesh for the analysis of C, N, P and K. The organic carbon concentration was estimated using Walkley *et al*., 1934, total nitrogen concentration was analyzed by sulphuric acid digestion followed by distillation and titration (Kjeldahl method using double beam UV spectrophotometer ELICO model SL 210), total phosphorus was determined by Vanadomolybdate yellow color method with the help of UV-visible spectrophotometer (Jackson, 1973), Potassium concentration was analyzed after the sample has been digested by sulphuric acid following Jackson, (1973) using flame photometer (Systronics model 128).

Statistical Analysis

Pearson correlation analysis was carried out between remaining leaf litter weight (%) and various nutrient concentration (%) i.e., N, P, K, C, C/N and N/P to test significant differences during decomposition of leaf litter at $p<0.05$ and $p<0.01$ level using SPSS 21.0 of 2012.

Results and Discussion

Initial chemical composition of leaf litter

The concentration of the initial composition of plant nutrients in all the 3 leaf species followed the trend as (1.12%) N > (0.21%) K > (0.098%) P in *M. azedarach*, (1.40%) N > (0.17%) K > (0.086%) P in *T. chebula* and (1.98%) N > (0.22%) K > (0.074%) P in *D. grandiflora* as shown in Table 1. Concentration of carbon was highest in the entire 3 leaf litter component and followed the pattern as *D. grandiflora* (65.50%) >*T. chebula* (60.50%)>*M. azedarach* (51.80%). Many earlier studies have reported an increase in N concentration during leaf litter decomposition across various forest and tree-plantation ecosystems Musvoto *et al*., (2000) and Ribeiro *et al*., (2000). In the present study, accumulation of nitrogen was observed until mid-phase in both *M. azedarach* and *D. grandiflora*. However, in *T. chebula* it was observed during a short period in the final phases of the study. In *M. azedarach* and *D. grandiflora*, N is accumulated during the initial phase of decomposition and released in the later phase but however in *T. chebula* N is released in the initial phase and immobilization takes place in the later phase. Several studies have reported an immobilization of N during the initial phase of decomposition Singh *et al*. 1990; Devi *et al*., 2010. At the end of one year, remaining phosphorous concentration was 78.99, 74.28 and 44.61 % in leaf litter of *D. grandiflora*, *M. azedarach* and *T. chebula* respectively. There was a sharp increase in the released of phosphorous in all the three species from Jan, (2017) to March, 2017. Even though there was a decrease in P (%) remaining in the whole experimental period and intermittent decreased (net mineralization) and increase net accumulation or immobilization was observed in some months of the decomposition period. In general, an increased in the P % remaining at some point of decomposition in all three zones of the same forest can be supported by work of Hasanuzzaman *et al*. 2014; Seta *et al*., 2016. In contrast, a rapid rate of P released was observed at the early decomposition period in the present study. Similar was observed by Seta *et al*., 2016. This is attributed to a significant portion of P in leaves are inorganic forms and leaching might explain a major part of the P released from the leaf residues (Nigatu *et al.,* 1994; Teklay *et al*., 2007). Otherwise, there was no significant difference observed between initial litter P content and respective P mineralization ($t=0.247$, $P=0.82$). As 10 is the ideal N/P ratio for decomposers Vogt *et al*. 1986, the highest initial N/P ratio in the leaf of *D. grandiflora* indicated that P could be the limiting factor in the leaf litter decomposition at this zone. The faster decrease of K (%) from the decomposing leaf litter in the present study was mainly because K is a non-structural element, highly mobile and most leachable cation during decomposition Seta *et al*., 2016. Moreover, K is not incorporated in to organic structures, and hence is less affected by leaf chemistry and soil faunal activity Ribeiro *et al*., 2000. From the present study it was determined that the initial litter chemistry strongly correlated with the K release in both sites ($r=0.879$, $p=0.021$) and it seems that initial litter content of K determines the release of K. Therefore, K is the limiting element which may highly determine the plant growth and development in the Semi-evergreen subtropical forest of Dikhu river.

Nutrients released during decomposition of leaf litter

A continuous increase of nitrogen was observed in *M. azedarach* and *D. gradiflora*. The increase was 121% (July) and 104% (September) of initial concentration respectively. In *M. azedarach* increased in N was exhibited during the first 8 months (April to July) followed by immobilization and thereafter nitrogen is released till March as shown in Fig. 1. However, in *T. chebula* there is a slow release of nitrogen from (April to March, 2017). In *D. grandiflora* nitrogen is released from April to August and then immobilized in September 2017, thereafter released at a faster rate from October till March. At the end of the experiment after 12 months, 64.8%, 66.4% and 81.3% of the original nitrogen are released from *M. azedarach, T. chebula* and *D. grandiflora* respectively. In form *M. azedarach,* the Nitrogen stock increased by 19.92 % over the initial values during the middle phase (243 days) of decomposition at upper zone showing the tendency of nitrogen immobilization. After 243 days, the nitrogen stock decreased slowly within the time during the course of the study period. At the end of the experiment after 12 months, 64.8%, 66.4% and 81.3% of the original nitrogen are released from *M. azedarach, T. chebula* and *D. grandiflora* respectively. Berg *et al*. 2006 identified an accumulation phase followed by a release phase for the litter N during decomposition among other models. The high rate of nitrogen released from the leaf litter of *D. grandiflora* could also be attributed to the influence of soil microarthropods. The sudden increase in nutrient remains at the end of the studies for nitrogen could indicate that soil N was being immobilized by the decomposing organism Alfred *et al*., 2001. Generally, the net accumulation of nutrient remaining at the end of the study may also suggest that some microorganisms acting on the resource, fed, died and decomposed on the litter, thus, increasing the nutrient quality. The decrease of initial carbon and nutrients concentration in early-stage observed from the present study may be due to the loss of the soluble forms of nutrients at the initial stages of decomposition which was also noted by Mahmood *et al*., 2007. On the other hand, a slower decrease of initial carbon and nutrients (%) towards the later stages of leaf litter decomposition may be due to microbial oxidation of refractory components, physical and biological fragmentation. Similar observations were noted by various authors Hasanuzzaman *et al*., 2014 and Mahmood *et al.* 2014. The P remaining (%) in the decomposing leaf litter of 3 species show a large temporal variability in the course of the decomposition experiment. In *M. azedarach* the concentration of P decreased during the first 4 months (0 to 92 days) over the initial one and simultaneously increased from July to September (90 days) sampling time as presented in Fig. 2. Thereafter, the concentration of P decreased till the end of the study period. In *T. chebula* the concentration of P decreased during the first 4 months over the initial one March to June (0 to 92 days) and then immobilization of P was simultaneous observed

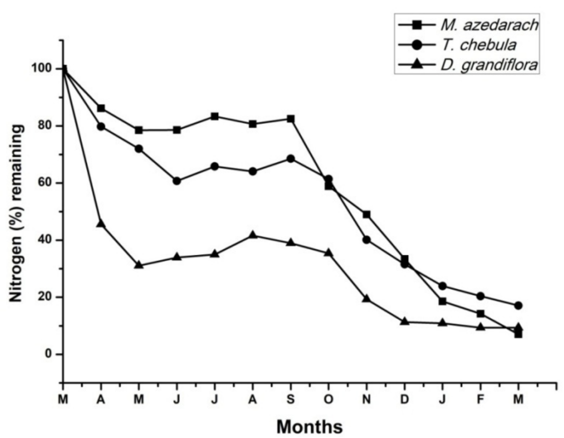

Fig. 1. Nutrient mass remaining N (%) content during decompositionof leaf litter of the three tree species.

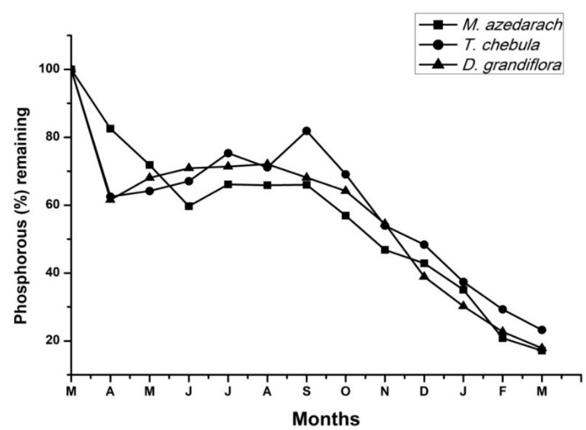

Fig. 2. Nutrient mass remaining P (%) content during decomposition of leaf litter of the three tree species.

from July to October (122 to 212) after that and then P mineralization's was observed from November to up to the end of the decomposition experiment (March). However, in *D. grandiflora* released of P started from the first 3 months than the P immobilization started from July to November (122 to 243) and slightly decreased from December to March (273 to 365). Despite the inconsistent released pattern, the P remaining (%) at the end of 365 days was 61.22 %, 58.13 % and 81.08 % by releasing 38.78 %, 41.87 % and 18 % from *M. azedarach*, *T. chebula* and *D. grandiflora* respectively. This pattern indicated the slow rate of P–mineralization throughout the course of leaf litter decomposition experiment. Fast released of K in the first phase of decomposition is observed in every type of litters irrespective of climatic zones and it was also observed in the present investigated forest site. After the first 2 months of decomposition, the present study observed 14.29 – 52.39 %, 47.06 – 64.71 % and 18.19 – 59.80 % lower concentration of K in *M. azedarach*, *T. chebula* and *D. grandiflora,* respectively as depicted in Fig. 3. There observed a rapid decreased of K remaining (%) in the first 2 months (0 to 60 days) indicating first K mineralization into the soil system at three zones. Thereafter, a drastic decreased in K remaining % was noted from June to September. Thereafter, increasing again from October to November and apparently, a slow decrease continues till the end of the decomposition period. At the end of the experimental period, K remaining % was found to be 28.57 %, 17.64 %, and 18.18 % by releasing 71.43 %, 82.36 % and 81.82 % in the soil system from *M. azedarach*, *T. chebula* and *D. grandiflora*. The decreased in K % was much higher in the rainy season than the remaining season. In *M. azedarach* there was a rapid rate of C loss from the decomposing leaf litter in the first 7 months (0 to 184 days) as illustrated as given in Fig. 4. Simultaneously C remaining (%) in *M. azedarach* decreases eventually up to till the end of the study period In *T. chebula,* rapid loss of C was observed in the first 7 months (0 to 184 days). However, in *D. grandiflora* there is a continuous rapid loss of C starting from the beginning until the end of the experiment. At the end of 365 days of decomposition period, 12.2 %, 24.96 % and 11.48 % of the initial C concentration was remained by releasing 87.8, 75.04 and 88.52 % into the riparian soil system from the leaves of *M. azedarach*, *T. chebula* and *D. grandiflora* respectively. As a matter of fact, the C released from the organic matter of leaf litter increases as the decomposition period increases in all the three zones of the forest. At the end of 365 days of decomposition period, 43.62 %, 62.44 % and 52.21 % of the initial C concentration was remained by releasing 56.38 %, 37.56 % and 47.79 % into the soil system from *M. azedarach*, *T. chebula* and *D. grandiflora* respectively. C/N ratios decreased over time in each leaf litter *viz*., from 46.25:1 to 80.71:1, 43.21:1 to 23.46:1 and 34.47:1 to 40.71:1 in *M. azedarach, T. chebula* and *D. grandiflora* respectively. Pearson correlation analysis between remaining biomass (%) and Nutrient concentrations as shown in Table 2 indicated that in *M. azedearch*, the concentration of N, P, K, and C were found to be positively significant at $p<0.01$ and N/P was positively significant at $P<0.05$

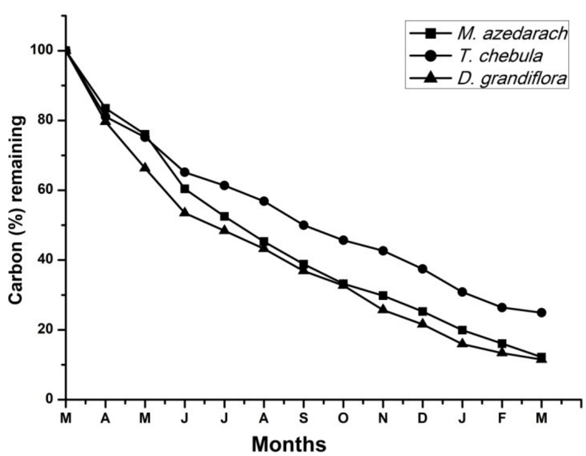

Fig. 3. Nutrient mass remaining C (%) content during decomposition of leaf litter of the three tree species.

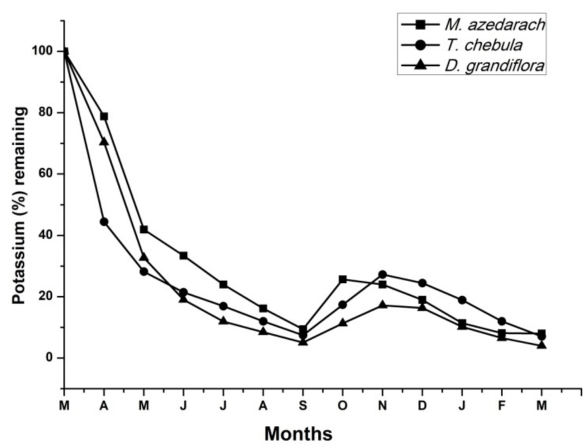

Fig. 4. Nutrient mass remaining K (%) content during decomposition of leaf litter of the three tree species.

whereas, C/N was found to be insignificant. In *T. chebula* the concentration N, P, K, C and C/N with the remaining biomass were found to be positively significant at $p<0.01$ whereas, N/P was found to be insignificant in case of *D. grandiflora* N, P, K, C, and N/P were found to positively significant at $p<0.01$ and C/N was found to be insignificant. At some points of decomposition during the rainy season, increased initial nutrients (N, P, and K) concentration in decomposing leaf litter were observed. This phenomenon is attributed to immobilization in the residual leaf litter (microbial or non-microbial) acting the decomposing leaf litter as a surface for fungi or heterotrophic organisms Hossain *et al*., 2011; Mahmood *et al*., 2014. In all the 3 species, the released of C follows a similar pattern by characterizing early immobilization in first 9 months (0 to 243 days) and released gradually (mineralization) till the end of the experiment. Generally, the decrease in released of carbon in early stage of an experiment may be due to the loss of soluble forms of nutrients at the initial stages of decomposition which was also noted in a study Mahmood *et al*., 2007; Seta *et al*. 2016. Carbon (C) and nutrients dynamics during the decomposition of plant residues are related to the availability of C and N in litter to the microbial population. Hill *et al*. 2006 alleged that litter with higher C/N ratio had a greater labile fraction and low mobility of and thus it decomposed more slowly than plant materials with low C/N ratios at the initial months. The concentrations of N, P and K in leaf litter at three zones increased consistently until the end of the study however the magnitude increase differs amongst the three species. Variation in concentrations of nutrient elements reflected the seasonal trend in the amount of litterfall and the concentration of elements in the litter as was also observed Muoghalu *et al*., 1993. Potassium and Phosphorous had their maximum concentrations in the dry season although recorded a high concentration of P and K in litter in the wet season. High potassium content could be due to lack of rainfall during these months. Potassium is easily leached from leaves and litter by rainwater Muoghalu *et al*., 1993. The lower content of highly mobile nitrogen might be due to leaching with rainwater, and lower Mg content in leaf litter possibly reflected the chlorophyll decay which confirms findings.

Nutrient inputs/returns to the soil of riparian forest from leaf litter decomposition

The nutrient input (kg $ha^{-1}yr^{-1}$) to the riparian forest soil by the three-leaf litter *viz*., *M. azedarach, T. chebula* and *D. grandiflora* were 48.52, 57.10 and 76.54 respectively for N, 4.24, 3.50 and 2.81 for P, 9.09, 6.92 and 8.50 for K, 2244.40, 2464.20 and 2532.60 for C. Elements returned to soil through litterfall constitute one of the most important links in matter and energy balance in forest ecosystems, in ad-dition to acting as a mechanism through which plant communities influence soil cover Augusto *et al*. 2002; Jonczak *et al*., 2012. In nutrient-poor forest stands, the annual return of elements to soil is a critical factor in their turnover that determines the stability of ecosystems. Most of the nutrient pools gradually released during litterfall decomposition are reincluded in biological turnover. Some amounts can be leached beyond the reach of root systems or

Table 1. Initial leaf litter composition (%) of three dominant tree species.

Species	N	P	K	C
M. azedarach	1.12±0.09	0.098±0.003	0.21±0.01	51.8±2.63
T. chebula	1.40±0.04	0.086±0.004	0.17±0.01	60.5±2.08
D. grandiflora	1.98±0.10	0.074±0.003	0.22±0.01	65.5±2.62

Table 2. Coefficient of correlations (r) values for remaining biomass (%) and leaf litter chemistry at the initial month in *M. azedarch, T. chebula* and *D. grandiflora*

Species	N	P	K	C	C/N	N/P
M. azedarach	0.940**	0.969**	0.818**	0.971**	-0.379	0.610*
T. chebula	0.961**	0.858**	0.744**	0.996**	0.868**	-0.548
D. grandiflora	0.856**	0.902**	0.775**	0.981**	0.072	0.736**

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

released into the atmosphere. The annual influx of elements to soil with litterfall is a resultant of litter mass and its chemical composition. The annual nutrients input/return (kg ha^{-1} yr^{-1}) of the elements to the forest floor of the riparian forest of all the three species followed the same trend as: C > N > K > P as observed by Jonczak *et al*., 2016 riparian forest in the area of Middle Pomerania. Organic carbon which constitutes about 50 % of dry weight of organic litter always comes in the largest amount. Similar to our observation was obtained by Jonczak *et al*., 2016 in *Alnus glutinosa* grown in the riparian forest of Pomerania where they reported the annual flux of C ranged from 1874.35 to 2312.26 kg ha^{-1} yr^{-1}. Fluxes of nitrogen associated with leaf fall are an important component of the internal N cycle of a forest ecosystem. Aerts 1996 suggested that they are determined largely by the physiological and anatomical characters of the main tree species. The initial concentration of plant nutrients in litterfall is important in determining the rate of decomposition and the amount of nutrients released to the soil during such decomposition. Therefore, the quality of litterfall, particularly N, was probably affected by the concentration of N in the soil and also due to the nature of the tree. The nutrient flux within the study site had nitrogen with highest flux due to nutrient input. Lower quantity of potassium may be due to leaching during the rainy season and also the greater number of days associated with a wet season Reinaldo *et al*. 1995. The amount of nutrient flux corresponded with the dry weight of litter produced. Nwoboshi *et al*., 1981 made a comparison of the nutrient contents in the foliage and the litter and suggested that not all the elements taken up by the foliar component of the shoot returned to the forest floor through litterfall.A noticeable increase in all the nutrient concentration at the early stages of decomposition may be due to (1) the activity of microorganism who fed, died and decomposed on the litter, thus, increasing the nutrient content, and (2) period of low rainfall where leaching away of the nutrient was affected. This is in accordance with the observation by Frioretto *et al*. 1998 that microbial activity can be limited by litter moisture content. However, where there is a high concentration of aerobic organisms, nutrient release through decomposition will continue because these organisms are active when there is high aeration.The result indicated a higher rate of N, P and K. A similar trend has been observed by Adejuyigbe, 2000 in the humid tropical forest. This rapid release could be attributed to the rapid loss of water-soluble compounds.

Acknowledgements

The first author is thankful to University Grant commission sponsored SAP-DRS-III, New Delhi Government of India for providing financial assistance by appointing as the project fellow.

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