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Full Research Article

Characterization and Evaluation of Hedges and Multipurpose Trees for Their Leaf Litter Decomposition Kinetics and Nutrient Release Patterns in the Indian Himalayas

B. P. Bhatt[1], Brajendra Parmar[2], L. J. Bordoloi[3] and Ranjan Bhattacharyya[4*]

[1]ICAR-Research Complex for Eastern Region, Patna, Bihar (800 001), India
[2]Indian Institute of Rice Research, Rajendranagar, Hyderabad, Telengana State (500 030), India
[3]Division of Soil Science, ICAR Research Complex for NEH Region, Umiam, Meghalaya (793 103), India
[4]NRL, Indian Agricultural Research Institute, Pusa, New Delhi (110 012), India

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Correspondence to

*E-mail: ranjan_vpkas@yahoo.com

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Abstract

In a field experiment having 33 plots under 1.55 ha area, although plots under agroforestry systems have huge potential for increased biomass productivity and soil conservation, little information is available on decomposition behaviour of leaf litters from different hedges and multipurpose trees (MPTs) in the Indian sub-Himalayas. Hence, an experiment was carried out to study the growth performance, biomass production, annual nutrient accumulation and rate kinetics of leaf litter decomposition of six promising hedgerow species and four MPTs in the Eastern Himalayas, India with three replications in randomized block design (RBD). Significant ($p<0.05$) variations were observed for survival and growth performance of hedges and MPTs. Significant variations were also recorded for biomass production between species. Hedge species had significantly higher biomass production and nutrient concentrations compared with the MPTs. Among all species, biomass production by *Crotolaria tetragona* was highest. On average, hedges accumulated 59.68, 11.95 and 28.31 kg ha^{-1} yr^{-1} of N, P and K, respectively, whereas MPTs contributed only 18.13, 0.77 and 7.18 kg ha^{-1} yr^{-1}, respectively. The decomposition pattern of different leaf litter represented triphasic phenomena, wherein hedgerow litter reached the peak of the rapid decomposition phase within two months. Cumulative decomposition of the leaf litter from MPTs was considerably less within the same time frame. Thus, planting of hedges is recommended under agroforestry system in the Indian sub-Himalayas.

1. Introduction

Humid tropical forests are characterized by relatively high precipitation and temperatures with a small annual variation in photoperiod. Nutrient cycling in these forest ecosystems has resulted in marked accumulations of the nutrients in plant biomass and litter as opposed to the soil (Brinkmann, 1983). For this reason the vegetative biomass of these forests is critical in the maintenance of soil fertility. Various multipurpose trees viz., *Alnus nepalensis*, *Gmelina arborea*, *Chukrasia tabularis*, *Michelia champaca* along with nitrogen fixing hedgerow species such as *Flemingia macrophylla*, *Tephrosia candida*, *Desmodium rensonii*, *Cajanus cajan*, *Indigofera tinctoria*, *Crotolaria tetragona*, etc. are often used in agro-ecological regions for multitude of benefits in terms of soil fertility build up, soil and water conservation and augmentation of biomass for mulch or as fodder and fuel (Laxminarayana et al., 2006). Considerable quantities of nutrients in organic form reach the soil through litter fall, below ground root turnover and, in agroforestry systems, as prunings (Szott and Kass, 1993). Hedge species have also been found suitable for soil conservation and sustainable crop production in rainfed agriculture (Kiepe, 1995). All such benefits that can be derived from hedgerow species and MPTs have made them integral components of hill farming systems. The leaf litter-fall can prove to be a vital agricultural resource for vast, complex, diverse and risk prone inhabitants of hilly ecosystems as it can add substantial amount of nutrients through recycling in the upper soil horizons considered as life line of agriculture. Hence, the litter-fall quantification and nutrient release dynamics will be an important study for agro-ecosystem restoration and biomass production assessment (Bray and Gorham, 1964).

Various investigations have been carried out on litter production

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by MPTs and hedgerows in agroforestry systems and have been considered as important aspects of nutrient recycling of such terrestrial ecosystems (Bray and Gorham, 1964; Toky and Singh, 1993). Even in traditional agriculture, one year cropping of *Flemingia vestita*, a lesser known legume of food value, could add up to 200 kg N ha^{-1} yr^{-1} (Gangwar, 1987). Other important issues for using these species are their utility as a mulch layer in an agroforestry system or as a bio-ameliorant or nutrient accumulator (Budelman, 1988). The gradual decay and decomposition of litter can find them suitable for incorporating them as vegetative barrier for soil erosion and run-off and leaching losses, whereas, the nutrient release dynamics can supplement nutrients removed by the annual crops (Budelman, 1988). Differently, the decomposition rate and pattern also can guide long term weed management under such systems such as when the decomposition is almost constant resulting in less material thereby moderating soil temperature and preventing proliferation of weed flora (Budelman, 1988). Although short-term rates of decomposition differ between different organic materials, Aber et al. (1990) suggested that in the long-term, decomposition of different materials may be similar due to similarities in carbon chemistries of the material remaining after initial decomposition. Aber et al. (1990) further stated that high lignin and polyphenol concentrations in the leaves of certain plant species would directly influence the rate of turnover of such material in an ecosystem. From a quality perspective the rate of breakdown of litter can be significantly influenced by the presence of phytotoxic accumulations of ionic species.

The amount of nutrients in biomass is considerable where these systems are fertilised, the nutrients recycled in litter can exceed the annual fertiliser input. However, frequent pruning which is commonly practiced in alley cropping systems often reduces total biomass production, nitrogen fixation (Duguma et al., 1988) and the production of Ca and Mg-rich woody tissue (Szott and Kass, 1993). In general, litter characteristics are not only governed by its constituents but to the edaphic characteristics such as rainfall and temperature. Some workers found differential litter production and decomposition which is also predicted by changes in temperature. There is a strong likelihood of differential pattern of leaf litter-fall for important hedgerows and MPTs. Therefore, we hypothesized that (i) there would be relative differences in leaf litter-fall and their decomposition behaviours of hedgerows and MPTs and (ii) there would be strong relationships between temperature and rainfall characteristics on leaf litter-fall of hedgerows and MPTs.

Importantly, to integrate hedgerow species or MPTs in farming systems, it is imperative to know their decomposition rate since it will provide the baseline information on supplementation of nutrients to crops of varying durations. As such the relationships among hedgerows and MPTs for differential decomposition pattern will be an interesting area of investigation. Keeping this fact in view, the objectives of this study was (i) to find the relative differences in leaf litter fall behaviors of hedges and MPTs (ii) to assess differential patterns in their decomposition and decay rates and (iii) to find the relationships between temperature and rainfall characteristics on leaf litter-fall of selected hedgerows and MPTs.

2. Materials and Methods

2.1. Site

The experiment site was located in between 25°39′ 25°41′ N latitude and 91°54′ 91°63′ E longitude. The altitude of the farm ranges from 900 to 950 m amsl. The climate of the area is humid subtropical with a mean annual rainfall of 2393.8 mm. On average, 90% of the total rainfall is received during April–October. The mean maximum and minimum temperature is 29.2 °C (June) and 6.07 °C (January), respectively. The soil (acidic Alfisol) of the experimental area was sandy loam and phosphorus deficient (Majumdar et al., 2004).

About 10 ha of fallow land were taken up for rehabilitation through agroforestry interventions in the year 2001–2002. Average soil depth was $\geq$1.0 m and the slope of the area ranged from 6.4 to 6.8%. Contour bunding was followed for soil and water conservation across the slope at a vertical interval of 3 m and also for gradual conversion of hill slope into terraces (Singh, 1990).

2.1.2. Experimental details

Out of the 10 ha of area, about 1.55 ha area was selected and divided into small plots, each of 500 m^2 area. All 33 plots were made to plant six hedge species (*Cajanus cajan*, *C. tetragona, D. rensonii*, *F. macrophylla, I. tinctoria* and *T. candida)* and four MPTs (*A. nepalensis*, *C. tabularis*, *G. arborea* and *M. champaca*). There was a control (without a tree) plot. These 11 plots were replicated thrice in a randomized block design (RBD). Hedge species were planted as a thick row on contour bunds whereas; MPTs were planted on contours across the slope at 5×5 m^2 distance from plant to plant and row to row, respectively. While making the plots, care was taken to ensure similar slope conditions (average 6.58°) and exposure.

Plant density for hedge species ranged from 773–833 numbers $plot^{-1}$ with highest to *C. tetragona* and lowest to *D. rensonii*, respectively. In case of tree species, 30 seedlings were accommodated in each plot. A uniform basal dose of 0.5 kg diammonium phosphate (DAP) and 10 kg farmyard manure (FYM) was applied in each pit (0.60×0.60×0.75 m^3) at the time of planting. Leaf litter was collected from MPTs (three years old) and hedgerow species (one year old). The biomass production in each species was recorded using simple quadrate method. Litter samples were oven dried at 65 °C. Nitrogen content in the foliage was determined by micro-kjeldahl method. Phosphorus and K content was determined following the methodology of Jackson (1973).

2.1.3. Litter decomposition

Standard litterbag technique was followed to study the decomposition of leaf-litter (Bocock and Gilbert, 1957). Quantity of leaf-fall was studied by placing 120 numbers of traps on the surface floor. The litterbags were filled with fresh leaf-litter maintaining an approximate dry litter weight of 0.02 kg in each bag. For each species, 120 numbers of litterbags were used. The litterbags were kept on the surface at different places at the vicinity of the respective species. At 15 days interval, 5 litterbags of each species were withdrawn randomly. The bags were worked to remove adhering soil particles. Extraneous materials like roots were removed and the dry weight of litter residue remaining in each bag was recorded by drying it at 65 °C. Traps constituted of catchment-nylon net kept litter off the ground inhibiting detritivorous activities. Traps were positioned in mid-September prior to leaf-fall and litter samples were collected at two-week intervals. Twenty litter bags containing each species were randomly collected each fortnight during October and then monthly until June, when all leaf material had disappeared. Soil and debris were carefully removed from outside of each bag. Leaf material from litter bags were dried at 80 °C for 48 hrs and weighed to determine the remaining biomass.

A known amount of air dried leaf litter (0.02 kg) of each species was put into 1×1 m^2 quadrant size traps. For each species, 120 litter bags were prepared. After 30, 60, 90, 120, 150 and 210 days of placement of samples, six litter bags were recovered at random. Three sub samples from each leaf-litter species were retained for determination of the initial nutrient composition. The monthly nutrient input to the forest floor through each litter fraction was computed by multiplying monthly values of each fraction mass with each corresponding nutrient concentration from each forest site and transported to the laboratory.

For easy calculation and expression, the weight loss values at one month's interval were considered. Although the experiment was designed to continue for one year, the decomposition was completed within seven months (December 2004 to June, 2005) and, therefore, the decomposition-experiment was terminated after that. The oven-dried samples were powdered for nutrient analysis. The nutrient concentration (N, P and K) was determined following the method prescribed by AOAC (Anon, 1995). For each litterbag, concentration of N, P and K was multiplied by the fraction of the original litter mass (dry weight) remaining to obtain the amount of each nutrient remaining in each sample period. This product was as a percent of the original content of each nutrient. The mean percentage of each nutrient remaining was obtained from litter bag replicates for each sample period.

2.1.4. Decomposition rate kinetics

From the weight loss values recorded for leaf litter of various species at different time lapses, per cent cumulative decomposition (PCD) was calculated. The PCD values were plotted against time to obtain first order rate kinetic as proposed by Frost and Pearson (1961). The equation is represented as:

$$\log (Co\text{-}C)=\log Co-(k/2.303)^{*}t$$

Where, k is the rate constant/decay rate (Day^{-1}); Co is the total decomposable material at time (t)=0; C is the cumulative decomposition (i.e. weight lost) at time t; and t is the time from the start of decomposition. Half-life of the decomposing material was calculated by the equation (Bockheim et al., 1991):

$$T_{1/2}=0.693\ k^{-1}$$

Where, k is decay rate constant.

2.1.5. Statistical analyses

The upper and lower limits of litter-fall were estimated as standard errors. The data on mean annual litter-fall amounts, mass loss after 210 days and initial chemical composition of fresh leaf litter were analysed using two ways ANOVA. The multiple comparisons were determined with the least significant differences (LSD) test at a significant level of 0.05, 0.01 and 0.001. The exponential decay parameter was calculated from the linear regression of the natural log of mass remaining over time. Different regression analysis was carried out to test the significance of nutrient released over decay rate constants with slope and intercept to find the prediction equation for nutrient release on input of decay rates. Most statistical analyses were carried out using extended EXCEL data analysis programme of Windows XP Version, Inc. Microsoft Corporation.

3. Results and Discussion

3.1. Growth performance of hedgerow species and MPTs

Survival percentage in hedge species ranged from 60–80%. While *D. rensonii* had lowest survival, *C. tetragona* and *T. candida* showed highest survival (80% for both species) (Table 1). Among various MPTs, *A. nepalensis* had highest survival (~71%) whereas; *C. tabularis* had lowest (55%). Significant variations were recorded for survival percentage between species. Plant density for hedgerow species ranged from

Table 1: Growth performance of different hedgerow species and multipurpose tree species in the Indian sub-Himalayas

Plant species	Survival	Plant density ha^{-1}	Plant height (m)	Collar diameter (cm)
Hedge species				
Cajanus cajan	75.0±8.5^{a}	18,660.0±112.5^{a}	1.79±0.049^{a}	2.23±0.25^{a}
Crotolaria tetragona	80.0±12.5^{ab}	17,565.0±169.2^{b}	1.61±0.332^{abcd}	3.80±0.75^{b}
Desmodium rensonii	60.0±15.0	15,460.0±140.4^{c}	1.28±0.108^{bd}	2.50±0.67^{ac}
Flemingia macrophylla	80.0±10.0^{ab}	18,030.0±139.2^{a}	1.17±0.123^{bd}	1.61±0.40^{ad}
Indigofera tinctoria	70.0±20.0^{a}	16,619.0±150.0^{bc}	1.55±0.046^{cd}	2.73±0.33^{bc}
Tephrosia candida	80.0±15.0^{b}	17,750.0±179.0^{ab}	1.05±0.253^{d}	1.53±0.25^{d}
Multipurpose tree species				
Alnus nepalensis	70.56±10.40^{b}	400.0±0.00^{a}	3.12±0.96^{a}	7.38±2.04^{a}
Chukrasia tabularis	45.00±15.00^{a}	400.0±0.00^{a}	0.83±0.31^{d}	2.43±0.70^{c}
Gmelina arborea	50.83±10.23^{a}	400.0±0.00^{a}	1.94±0.13^{b}	7.52±1.35^{a}
Michelia champaca	70.00±10.00^{b}	400.0±0.00^{a}	1.24±0.49^{c}	4.52±0.69^{b}

Within a column, means followed by same letter for a particular plant type (hedge species and MPTs) are not significantly (p<0.05) different

15,460-18,660 numbers ha^{-1} with lowest of *D. rensonii* and highest of *C. cajan*, respectively. In case of all MPTs, planting density was 400 seedlings ha^{-1}. Among various hedge species, growth (in terms of height) was highest for *C. tetragona* (1.79 m) and lowest for *T. candida* (1.05 m). Among MPTs, *A. nepalensis* exhibited highest height growth (3.12 m) that was significantly higher than other MPTs. Collar diameter of hedge species was highest (3.80 cm) in *C. tetragona* and lowest (1.53 cm) in *T. candida*. Among trees, *G. arborea* exhibited highest collar diameter growth (7.52 cm), followed by *A. nepalensis* (7.38 cm) (Table 1).

3.2. Leaf litter-fall characteristics

Monthly leaf litter-fall characteristics varied widely among the hedges (Figure 1) and MPTs (Figure 2). Multipurpose trees produced significantly less leaf litter-fall than hedges. For MPTs, the leaf litter fall of *Alnus* (0.48 kg m^{-2} yr^{-1}) was significantly higher than *Michelia* (0.32 kg m^{-2} yr^{-1}) and

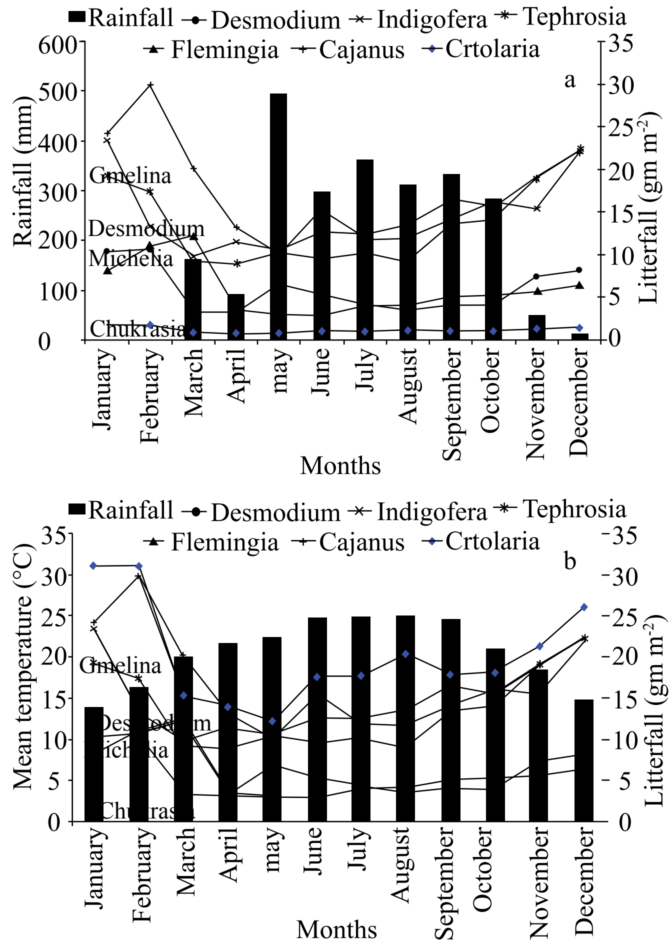


Figure 1: Monthly leaf litter-fall of hedgerows with mean monthly (a) rainfall and (b) air temperature

Chukrasia (0.29 kg m^{-2} yr^{-1}). Among the hedgerows, the leaf litter-fall varied of *Crotolaria* (0.24 kg m^{-2} yr^{-1}) was similar to *Cajanus* (0.20 kg m^{-2} yr^{-1}), but was significantly higher than *Indigofera* (0.18 kg m^{-2} yr^{-1}), *Tephrosia* (0.16 kg m^{-2} yr^{-1}), *Desmodium* (0.07 kg m^{-2} yr^{-1}) and *Flemingia* (0.07 kg m^{-2} yr^{-1}). Monthly variation of leaf litter-fall indicated that 30% of the total leaf litter production of *Crotolaria*, 26% for *Flemingia*, 21% for *Desmodium*, 21% for *Indigofera*, 23% for *Tephrosia* and 24% for *Cajanus cajan* were obtained in just two months (January and February). Among MPTs, 31% for *Alnus*, 31% for *Gmelina* and 27% for *Michelia* were collected during those two months.

Leaf biomass production was highest (2.42 t ha^{-1}) for *C. tetragona*, followed by *F. macrophylla* (2.32 t ha^{-1}) (Table 2). Lowest biomass (0.68 t ha^{-1}) was recorded in *D. rensonii*. Among trees, *A. nepalensis* had highest biomass (1.22 t ha^{-1}), followed by *G. arborea* (1.01 t ha^{-1}). Leaf biomass differed significantly among species. However, biomass production in *C. tetragona* and *F. macrophylla* was similar. Among MPTs,

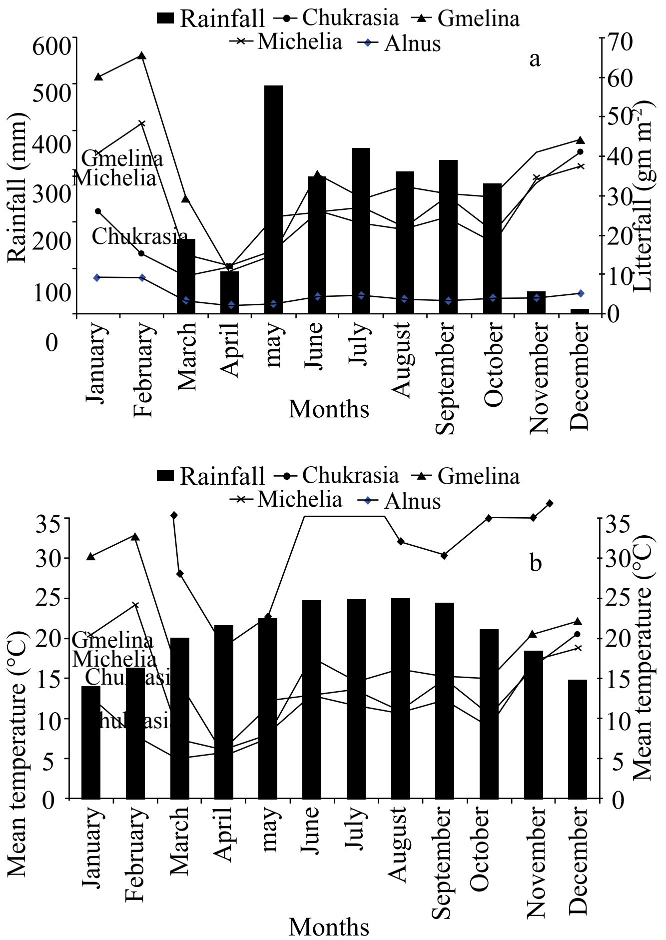


Figure 2: Monthly leaf litter-fall of multipurpose trees (MPTs) with mean monthly (a) rainfall and (b) air temperature

A. nepalensis produced significantly higher biomass compared with other tree species. On average, hedge species contributed 1.55 fold higher biomass production compared with MPTs.

Relationship between mean monthly rainfall (mm) and leaf litter-fall (kg m^{-2}) of hedges showed a negative correlation for *Cajanus* (-0.72; p<0.01), *Crotolaria* (-0.59; p<0.05), *Desmodium* (-0.59; p<0.05), *Flemingia* (-0.56; p<0.05), *Indigofera* (-0.68; p<0.05), and *Tephrosia* (-0.78; p<0.05). For MPTs *Alnus* (-0.57; p<0.05), *Chucrasia* (-0.65; p<0.05), *Gmelina* (-0.64; p<0.05) and *Michelia* (-0.65; p<0.05) had negative correlations. The magnitude of negative correlation between hedges and MPTs with rainfall (mm) was almost similar.

Significant negative correlations were also obtained from the relationships between leaf litter-fall with air temperature (a mean of minimum and maximum temperature). Leaf litter-fall from *Cajanus* (-0.37; p<0.05), *Flemingia* (-0.69; p<0.05) and *Indigofera* (-0.71; p<0.05) significantly decreased with mean air temperature. Significant negative correlation were also obtained with two MPTs [*Chucrasia* (-0.48; p<0.05) and *Michelia* (-0.74; p<0.05). The magnitude of negative correlation between leaf litter-fall of MPTs with mean air temperature was almost similar to that between leaf litter-fall of hedges with mean air temperature.

Table 2: Biomass production and annual nutrient accumulation by hedge species and multipurpose tree species in the Indian sub-Himalayas

Plant species	Leaf biomass (t ha^{-1})	Annual nutrient accumulation (kg ha^{-1})		
		Nitrogen	Phosphorus	Potassium
Hedge species				
Crotolaria tetragona	2.42± 0.070^{a}	88.65± 2.32^{a}	18.65± 1.64^{a}	44.81± 1.11^{a}
Tephrosia candida	1.63± 0.061^{b}	62.19± 1.19^{b}	8.30± 0.58^{b}	31.75± 0.73^{b}
Flemingia macrophylla	2.32± 0.014^{a}	77.72± 1.85^{a}	15.78± 0.31^{ab}	33.87± 0.31^{ab}
Indigofera tinctoria	1.81± 0.031^{b}	74.61± 1.31$_{a}$	17.75± 0.67^{a}	34.05± 0.43^{ab}
Desmodium rensonii	0.68± 0.010^{c}	27.01± 1.21^{c}	4.91± 0.12^{c}	12.00± 0.11^{c}
Cajanus cajan	0.82± 0.011^{c}	27.91± 0.67^{c}	6.28± 0.19^{bc}	13.38± 0.17^{c}
Mean	1.61± 0.73	59.68± 26.35	11.95± 6.34	28.31± 12.94
Multipurpose tree species				
Alnus nepalensis	1.22± 0.011^{a}	25.86± 0.92^{a}	1.34± 0.11^{a}	10.04± 0.09^{c}
Chukrasia tabularis	0.98± 0.034^{b}	17.64± 0.83^{b}	0.59± 0.001	7.26± 0.17^{b}
Gmelina arborea	1.01± 0.031^{b}	14.14± 0.45^{c}	0.40± 0.003	5.66± 0.001^{a}
Michelia champaca	0.93± 0.043^{b}	14.88± 0.37^{c}	0.74± 0.002^{b}	5.77± 0.002^{a}
Mean	1.04± 0.13	18.13± 5.37	0.77± 0.41	7.18± 2.04

Within a column, means followed by same lowercase letter for a particular plant type (hedge species and MPTs) are not significantly (p<0.05) different

Among MPTs, *Alnus* showed significantly higher leaf litter-fall due to more biomass production, although plant density (400 numbers ha^{-1}) was lower. Significantly, higher plant height (3.12 m) and higher collar diameter (7.38 cm) can be the probable reasons. Among the hedges, *Crotolaria* produced highest leaf litter fall and had significantly higher survival percentage (80%), plant density (17,565 numbers ha^{-1}), plant height (1.61 m) and collar diameter (3.8 cm) than all species. Bray and Gorham (1964), while comparing the leaf litter output, observed that species having higher plant density showed higher litter productivity. Higher litter production by certain hedges and MPTs may be due to various other factors such as age of the tree, leaf area, texture, canopy exposure, basal areas, etc. (Van Cleve and Noonan, 1957).

Higher occurrence of litter production in the months of January and February seemed to be directly related to drier period of the year and the formation of abscission layer due to severe monthly stress (Longman and Junik, 1974). However, in rest other months, the litter fall maintained a constant pattern. Litter-fall for MPTs was nearly equal to the lower range of litter production frequently encountered in some tropical rain forests elsewhere in the tropical and subtropical regions of the world (Bray and Gorham, 1964). However, for hedgerows it was well above the lower range frequently observed in other parts of the world (Bary and Gorham, 1964). Average leaf litter fall for MPTs was similar to that found in forests containing native deciduous trees in north-eastern and eastern US (ranging between 280−573 g m^{-2} yr^{-1}) and to the leaf fall of the warm temperate region 361 g m^{-2} yr^{-1}. Some of the trees, however, are evergreen or semi-evergreen in nature which shed their leaves throughout the year. Contradictorily, bimodal pattern of leaf fall has been reported by several workers (Addicotte and Lyon, 1973) in different types of forest.

Monthly leaf-fall pattern were same for both hedges and MPTs as the sites were same and other factors such as environmental saturation and soil moisture activity were also the same. The quantification of leaf litter fall was however, different because of plant density differences as also observed by Cooper (1982). In this study, sole exception was *Desmodium,* which although having less plant stand produced more litter-fall in January and February. This negative correlation with climatic parameters can be attributed to even distribution of litter production among the species. Similar negative correlation was reported by Murphy and Ingo (1986). Pruned biomass yield of hedge species ranged from 0.82−2.42 t ha^{-1} (Bhatt and Bujarbaruah, 2006), which was well within the range as reported by earlier workers for the same species (Sundriyal and Jamir, 2005; Bhatt et al., 2006). Thus, the first hypothesis was supported by the fact that despite subjected to same environmental and climatic conditions, the monthly leaf litter-fall pattern varied significantly among different species of hedges and MPTs.

3.3. Annual nutrient accumulation by hedge species and MPTs

Foliage of all hedge species had high concentration of N, P and K. Nitrogen concentration ranged from 3.35–4.12% in different hedge species with lowest in *F. macrophylla* and highest in *I. tinctoria*, respectively (Table 3). Phosphorus showed a range of 0.51–0.98% with lowest in *T. candida* and highest in *I. tinctoria*, accordingly. Potassium had a range of 1.46−1.95% with lowest in *F. macrophylla* and highest in *T. candida*, respectively. On average, foliage of *I. tinctoria* had the highest N and P concentration whereas; *F. macrophylla* had lowest N and K content.

Table 3: Nutrient content in leaf litter of hedge species and MPTs in Meghalaya, India

Plant species	Nutrient content (%)		
	Nitrogen	Phosphorus	Potassium
Hedge species			
Crotolaria tetragona	3.66±0.13[abed]	0.77±0.08[ab]	1.85±0.10[ab]
Tephrosia candida	3.82±0.17[acd]	0.51±0.04[d]	1.95±0.12[a]
Flemingia macrophylla	3.35±0.18[eb]	0.68±0.07[a]	1.46±0.15[c]
Indigofera tinctoria	4.12±0.22d[c]	0.98±0.09[c]	1.88±0.16[ad]
Desmodium rensonii	3.96±0.17[d]	0.72±0.06[a]	1.76±0.17[ad]
Cajanus cajan	3.42±0.15[e]	0.88±0.07[bc]	1.64±0.14[bcd]
Multipurpose tree species			
Alnus nepalensis	2.12±0.16[a]	0.11±0.01[c]	0.82±0.09[a]
Chukrasia tabularis	1.80±0.13[ab]	0.06±0.01[ab]	0.74±0.08[ab]
Gmelina arborea	1.40±0.12[c]	0.04±0.00[a]	0.55±0.07[c]
Michelia champaca	1.60±0.10[bc]	0.08±0.01[b]	0.62±0.06[bc]

Within a column, means followed by same letter for a particular plant type (hedge species and MPTs) are not significantly ($p<0.05$) different

In case of trees, N concentration in foliage ranged from 1.40−2.12%. Similarly, range of P and K was 0.04−0.11 and 0.55–0.82%, respectively. While *A. nepalensis* had the highest concentration of N, P and K, it was *G. arborea* which had the lowest amount of the same nutrients. Significant variations were recorded for all nutrients between species. Inter-comparing nutrient concentration of hedges and MPTs showed that hedge species had significantly higher nutrient contents than MPTs.

Foliage of *C. tetragona* added maximum N (~89 kg ha^{-1}), P (~19 kg ha^{-1}) and K (~45 kg ha^{-1}) into the soil. *D. rensonii* contributed the lowest amount of all nutrients, which was proportionate to the biomass production. Among various MPTs, nutrient accumulation of *A. nepalensis* was highest. Similar to nutrient concentration in hedge species, significant variations were observed for N, P and K accumulation by tree species. Annual accumulation of N and K by the leaf-litter of *G. arborea* and *M. champaca*, however, did not exhibit any significant variations (Table 2). Irrespective of species, hedges accumulated 3.3, 15.5 and 3.94 fold higher amount of N, P and K, respectively, compared to MPTs.

Leaf litter-fall has an important influence on physical, chemical and biological characteristics of soil and, thus, influences the nutrients present in soil resources. The litter forms an obligate nutrient layer and the quantity and quality of the nutrient depends on the type and amount of litter biomass (Anderson et al., 1983). Further, the balance between decay rates depends on litter quality, climate, moisture/aeration, faunal activity, microbial populations. Based on the quantity of residual mass left in the litterbags at the end of each fortnight, decay coefficients were higher for hedgerow species than MPTs. The potential nutrient returns in the form of a leaf litter are of the order of 80–120 kg N, 8–12 kg P, 40–120 kg K and 20–60 kg Ca for humid tropics of India as observed by Lupway and Haque (1998). In this investigation, 59.68 kg N, 11.95 kg P and 28.31 kg K was contributed by hedges. Accordingly MPTs contributed 18.13 kg N, 0.77 kg P and 7.18 kg K. In an another study, amount of leaf-fall and nutrient recycling in *Eucalyptus*, *Dalbergia sissoo* and *Leucaena leucophala* based agroforestry system showed a total return of 58 kg N, 48 kg K and 4.6 kg P ha^{-1} . Since, the material decomposed within seven months, we estimated the total amount of each nutrient that would accumulate in the soil. Agroforestry, therefore, promotes closer nutrient cycling as evident from the present investigation. Among the hedges, foliage of *C. tetragona* added maximum N (88.65 kg ha^{-1}), P (18.65 kg ha^{-1}) and K (44.81 kg ha^{-1}) into the soil. Nutrient release followed the order N>K>P for both hedges and MPTs. High initial content of N of hedges reflects its relative suitability as better substrate for microflora action. Higher amount of nutrient accumulation of hedges than MPTs is also related to its rapid mass loss.

Nitrogen content decreased in all species over the period, which may be attributed to higher demand for nitrogen for the intense microbial activity during the initial stages of decomposition. Another reason could be leaching of water soluble nitrogenous substances (Nykvist, 1963). Since the leaf decay rate varied for hedgerow and MPTs, rate constant also differed accordingly. Total N release was >80% for MPTs, irrespective of species. Although, hedges had faster decomposition rates, total nitrogen release ranged only from 51−56%. Hedgerow litter probably is constituted more of easily decomposable nitrogenous compounds than MPTs. Leaf litter of MPTs might be having slowly decomposable nitrogenous compounds such as lignin. Similar trend was observed for total release of P and K. The type and composition of organic matter applied, particularly the lignin/polyphenolic concentration influence the rate of formation of organic matter.

The P content also decreased in leaf litter gradually as the time progressed. Leaf-litter of hedgerow species had faster decrease in P content than MPTs. Faster decrease on P content could be attributed to the rapid loss of P bounded in easily leachable compounds. The absolute content of P in the leaf litter showed a biphasic pattern with the initial rapid decline phase, followed by a slow phase. However, concentration changes were not substantially enough to make greater changes in the absolute amounts owing to faster mass loss. The release of P from organic materials is difficult to model since there are strong interactions between the C, P and N cycles which determine patterns of immobilization and mineralization (Palm and Sanchez, 1990).

The K content also decreased and followed a biphasic pattern for hedgerows and MPTs. Since K is not structurally bound in the organic compounds, its quick leachability in water could be the major reason for the rapid decline in leaf litter. Rapid mass loss and its K content in the leaf litter could also be due to high rainfall coupled with high humidity, temperature and microbial activity. In the humid tropics, 50% or more K is released from pruning in less than a month, whereas Ca release is slow with turnover times often longer than one year (Palm and Sanchez, 1990; Swift et al., 1981).

The quality of organic matter can significantly influence the rate of release of nutrients other than N. Palm and Sanchez (1991) reported that the mineralization of P, K, Ca and Mg was faster from high quality *Erythrina* leaves than from low quality *Inga edulis* or *Cajanus cajan* leaves. Similarly, Constantinides and Fownes (1993) reported that including twigs with the leaf litter of *Calliandra calothyrus* and *Gliricidia sepium* reduced the short-term net N mineralization and release of available N from decomposing green manure. This effect would explain the relative quantities of nutrients in these materials vary greatly depending on tree species (Szott and Kass, 1993).

3.4. Leaf litter decomposition pattern

Proportions of cumulative decomposition values were plotted against time to study the pattern of decomposition (Figure 3 and 4). All hedge species had>50% decomposition within a period of 30 days with highest (64.65%) in leaf-litter of *C. tetragona* and lowest (58.2%) in *T. candida*. Within the same period, decomposition percentage of leaf-litter of MPTs ranged

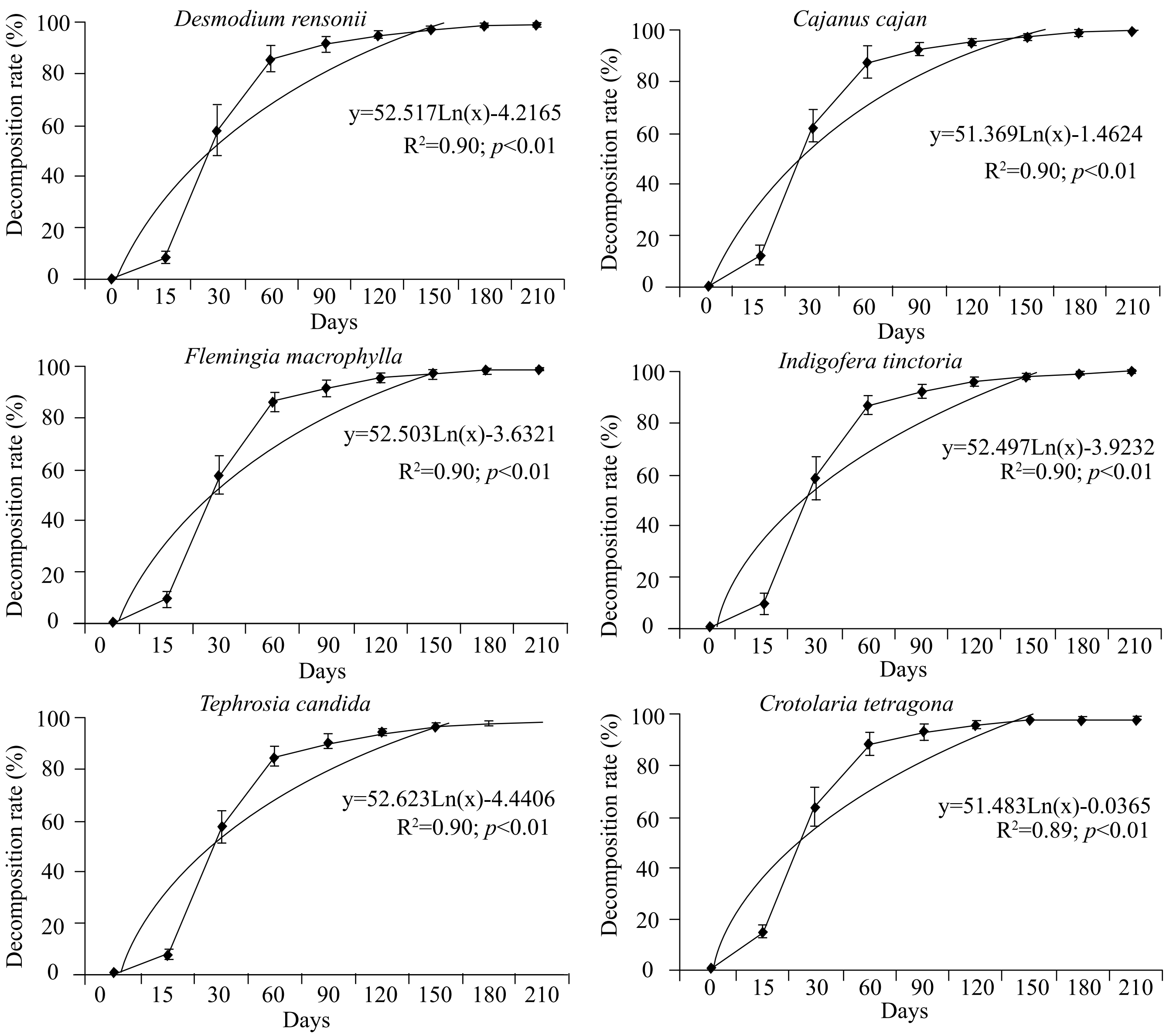


Figure 3: Leaf litter decomposition pattern of different hedge species, Eastern Himalaya, India (vertical bars representing ±SD)

from nearly 18 to 22% (Figure 4). Within 60 days,>80% decomposition was noticed for hedge species whereas, in case of MPTs, it ranged from ~64 to 75%. However, 90 days after experiment, the decomposition rate was>90% for all the hedge species and MPTs. Decomposition percentage was>95% for leaf litter of hedges and MPTs after 120 days of experimentation. Thereafter, more or less same pattern of decomposition was recorded for leaf litter of hedges and MPTs. Significant positive correlation ($p<0.01$) was recorded between air temperature and decomposition rate of leaf litter. Rainfall also showed significant positive correlation with decomposition pattern of leaf litter of hedge species ($p<0.01$) and MPTs ($p<0.05$).

Leaf-litter decomposition in hedges and MPTs showed a tri-phasic phenomena consisting of a rapid decomposition phase to start with, followed by a static phase and a slow degradation phase at the last (Sreekala et al., 2002). The onset of the static phase following the rapid decomposition phase reflects the virtual end of decomposition of the substrate (leaf litter). The 2nd phase (static phase) observed in this study can be termed as the humus formation phase. Irrespective of the species, it can be observed that the humus formation phase has almost twice the duration of the rapid decomposition phase. As all plant species under this study were exposed to the similar weather conditions as well as soil management practices, the residue (leaf litter) properties seems to be the sole factor responsible for their differential decay rates. Decomposition rate and nutrient release are governed primarily by residue properties

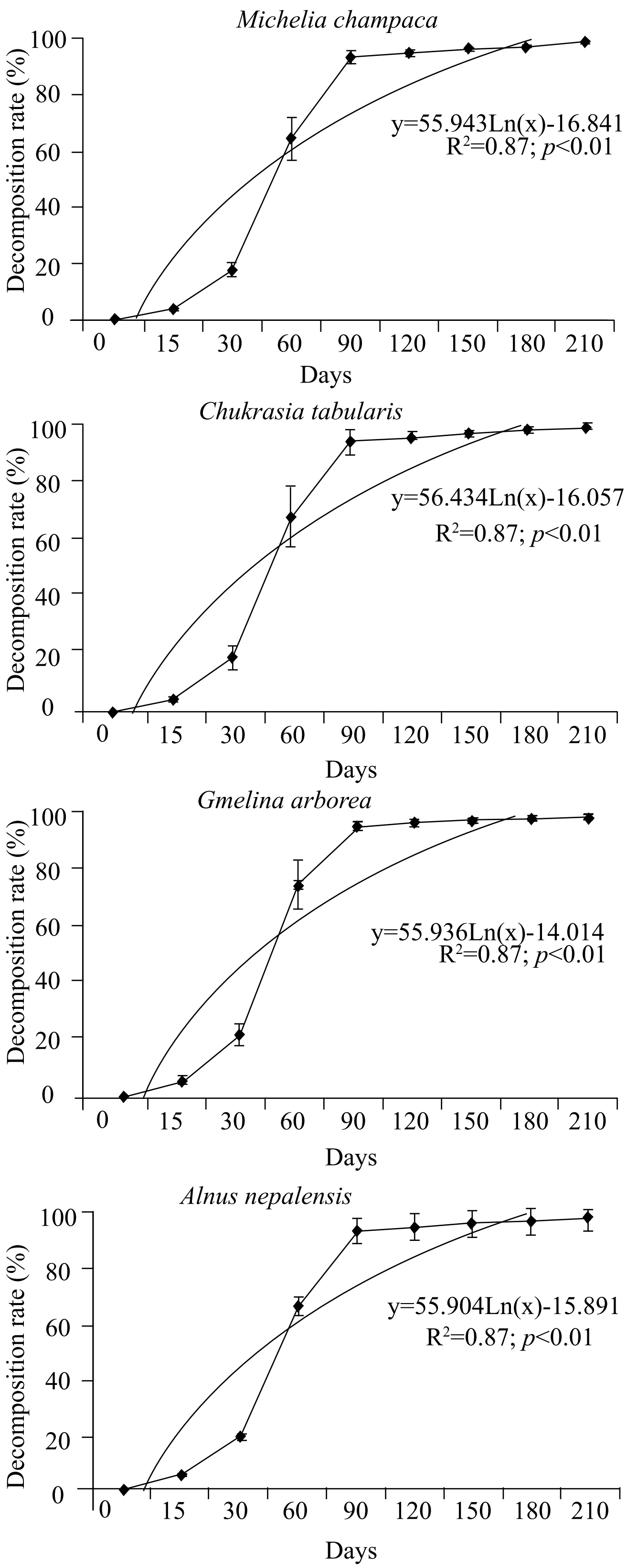


Figure 4: Leaf litter decomposition pattern of different multipurpose trees (MPTs), Eastern Himalaya, India

besides other factors such as weather conditions, soil and crop management practices etc (Palm et al., 2001).

In case of the hedgerow species, the maximum decay rate was achieved within the first two months from the start of decomposition, whereas in case of the MPTs, nearly three months was required for the decay rate to touch the peak. Extremely rapid decomposition rate underscores the utility of the hedgerow leaf mulch as efficient soil enricher as well as organic plant nutrient supplement, particularly for short duration crops. Leaf-litter of MPTs was also found to hold promise as fairly nutritive organic mulch for medium and long duration crops. Such a faster rate of decomposition in leguminous species was also reported by Perin et al. (2006), who estimated that about half of the nitrogen was released from sunhemp (*Crotalaria* spp.) residue applied to the maize crop. Leaf litter of all six hedgerow species under went more than 85% cumulative decomposition, recording a maximum of 89% in *Crotalaria* leaf litter. Contrarily, the cumulative decomposition of leaf-litter of MPTs within the same period was considerably less, with a maximum of only ~75% recorded in *Gmelina* leaf litter. This again confirms to the findings of earlier workers that the legume biomass exhibit low C:N ratio, higher concentration of soluble compounds, and low lignin and polyphenol content, which favour the rapid microbial degradation (Cobo et al., 2002).

Substrate's quality, climate, quantity and quality of decomposing organisms have been found to be the primary determinants of litter decay rates (Swift et al., 1979). The rate of decomposition of leaf litter, its decay constant and half-life revealed a marked difference. The hedgerow species took less time to disappear and as a result, its decay rate, half life was faster compared with MPTs. This could be due to rapid loss of water soluble fragmented components, followed by utilization of readily digestible constituents by the soil microbes as sources of energy (Islam and Weil, 2000). Average half-life of leaf biomass of MPTs was nearly 39.3 days compared to 25.0 days for hedgerow species. Leaf biomass of MPTs seems more recalcitrant in decomposition than hedgerows. In the initial period, decomposition and decay rate of litter-fall was very slow for MPTs, which increased with time. Thus, half-lives of litter-fall of MPTs were higher than hedgerow species, indicating that hedgerow species are better suited for use as leaf mulch and could fulfill the initial high NPK requirement of the crops. Hence, a portion of recommended dose of the NPK fertilizers to the crops could be saved.

Any strategy to utilize hedges and MPTs for utilizing as mulch material often considers its half life values. Mean half-life values for different hedgerow species followed a variable trend and the same could be arranged in the order of *C. tetragona* (22.19 days)<*I. tinctoria* (24.85 days)<*D. rensonii* (25.50 days)<*C. cajan* (25.66 days)<*T. candida* (25.69 days)<*F. macrophylla* (25.88 days). Among all hedgerow species, leaf-litter of *C. tetragona* was highly decomposable. Among the MPTs, half-life values of leaf-litter varied considerably and the same could be arranged as *C. tabularis* (35.43 days)<*G. arborea* (38.39 days) <*A. nepalensis* (40.33 days) <*M. champaca* (43.13 days). It indicates that leaf-litter of *C. tabularis* was fast decomposable compared to others and hence *C. tetragona* ($T_{1/2}$=22.19 days) is ideally suited for mulching more so due to its higher leaf biomass productivity (2.42 t ha^{-1}) and higher plant density (17,565 numbers ha^{-1}). The data obtained confirmed to a first order exponential decay curve and were highly significant ($p<0.05$). The coefficient of determination (R^2=0.90; $p<0.01$) could be explained by the exponential model of decay. The slope of the relationships and other statistical parameters such as decay rates (k) and $T_{1/2}$ proved to be useful in comparing the species. The second hypothesis was supported by the differences obtained for all the parameters among the hedges and MPTs.

3.5. Decomposition rate kinetics

Half-life period differed significantly for all species. Significant monthly variations were recorded for decomposition rate (g day^{-1}) in all hedge species except that of *C. tegragona*. On average, half-life period for hedges was 24.96 days with highest for *F. macrophylla* (25.9 days) and lowest for *C. tetragona* (22.2 days). Significant monthly variations were also observed for litter-N concentration in each species. Compared to initial concentration, ~56% of litter-N was lost during decomposition with highest (~58%) for *T. candida* and lowest for *C. tegragona* (~48%), respectively. Similar was the case for litter-P concentration. Mean litter-P loss was about 56%, with highest for *T. candida* (~59%) and lowest for *C. tetragona* (48%), accordingly. Significant monthly variations were also observed for litter-K concentration. On average, litter-K loss was ~52% with highest for *D. rensonii* (~59%) litters and lowest for *C. cajan* (~33%) litters. Among several hedge species, no significant variations were observed for decay rate and half-life, however, nutrient concentration exhibited significant variations (Table 4). *Crotolaria tetragona* had significantly higher litter-N concentration than *C. Cajan, T. candida* and *F. macrophylla* (Table 4).

In case of MPTs, significant monthly variations were observed for decay rate of leaf-litter of *G. arborea* and *M. champaca* whereas; half-life period showed significant variations for *Alnus nepalensis* and *Chukrasia tabularis* and for *Alnus nepalensis* and *Gmelina arborea* (Table 5). Mean half-life period of MPTs was 39.3 days. Among MPTs, litters of *M.* champaca had highest half-life (43.1 days) and *G. arborea* had lowest (35.43 days). Similar was the trend for N and P concentrations. On average, litter N and P loss was 88.6 and 88.5%, respectively. For both nutrients, highest loss was recorded in *M. champaca* and lowest in *G. arborea*, accordingly. Average K loss in leaf-liter was as high as 89.3% (Table 4). In general, decay rate (K) values for different leaf litters followed a fixed trend, irrespective of the plant species. As the decomposition progressed, decay rate values increased gradually till reaching a peak and then declined. However, no clear-cut differences in terms of magnitude of decay rates were observed between the hedgerow species and the MPTs.

3.6. Relationship between nutrient release and decay rate parameters

Decay rate can be an indicator of nutrient release pattern of leaf litter-fall. The litter decomposition rate was hypothesized to have in linear relation with the nutrient release pattern. In line with the hypothesis, the regression curves were significant and were linear for hedges (Figure 5). The decay rates were positively correlated with nutrient releases in case of hedges and negatively correlated in case of MPTs (and hence data are not shown). For MPTs significant inverse relationship was obtained for N, P and K release. The amount of N, P, and K release based on decay rate values for the period assessed were then predicted. The predicted N amount was significantly correlated with actual N amount obtained (Table 6). However, for P and K release, the predicted values were much higher than the actual P and K release. The following relationships were obtained for hedges that can predict nearly equal to the actual amount of N released.

N (%) release=22.30 k+1.28 for *Cajanus*
N (%) release=48.51 k+0.41 for *Crotolaria*
N (%) release=31.62 k+0.65 for *Desmodium*
N (%) release=42.33 k+0.71 for *Flemingia*
N (%) release=46.98 k+0.5 for *Indigofera*
N (%) release=42.05 k+0.5 for *Tephrosia*

However, coefficient of determination was highly significant for all variables (Table 7).

Since overestimation of variables is a common feature in any decomposition studies, we carried out regression analysis to test the nutrient release phenomenon over decay rates. We hypothesized that there would be linear relationships between decay rates and nutrient releases. One of the limitation in linear regression model is that independent variable is not measured without error. Error in the independent variable widens the slope of the regression. For MPTs, large amount of unexplained variability in decomposition rates could be

Table 4: Nutrient contents in decomposing leaf litter of different hedgerow species, Eastern Himalaya, India

Period (month)	Decay rate (g day^{-1})	Half life (days)	Concentration of litter-N at sampling time (%)	Concentration of litter-P at sampling time (%)	Concentration of litter-K at sampling time (%)
Crotolaria tetragona					
Initial	0	-	3.66±0.13	0.77±0.08	1.85±0.10
December	0.0347±0.0006^{a}	20.0±2.0^{a}	2.37±0.12^{a}	0.50±0.04^{a}	1.20±0.07^{b}
January	0.0375±0.0004^{a}	18.5±0.65^{a}	2.12±0.16^{ab}	0.45±0.06^{ab}	1.07±0.08^{a}
February	0.0321±0.0003^{a}	21.6±0.50^{ab}	2.00±0.11^{b}	0.42±0.05^{b}	1.01±0.05^{a}
March	0.0296±0.0002^{a}	23.4±0.45^{b}	1.94±0.18^{b}	0.41±0.03^{b}	0.98±0.04^{a}
April	0.0322±0.0005^{a}	21.5±0.50^{ab}	1.93±0.14^{b}	0.41±0.04^{b}	0.97±0.09^{a}
May	0.0289±0.0001^{a}	24.0±0.75^{b}	1.92±0.10^{b}	0.40±0.05^{b}	0.97±0.08^{a}
June	0.0263±0.0001^{a}	26.3±0.80^{b}	1.91±0.10^{b}	0.40±0.05^{b}	0.96±0.06^{a}
Mean	0.032 A	22.2 A	2.23 A	0.47 A	1.12 A
Tephrosia candida					
Initial	0		3.82±0.17	0.51±0.04	1.95±0.12
December	0.0291±0.0005^{ab}	23.8±2.0^{a}	2.22±0.15^{a}	0.30±0.05^{a}	1.13±0.13^{c}
January	0.0323±0.0004^{a}	21.5±0.66^{a}	1.90±0.16^{b}	0.25±0.06^{b}	0.97±0.12^{a}
February	0.0272±0.0003^{b}	25.5±0.40^{ab}	1.74±0.18b^{c}	0.23±0.03^{b}	0.89±0.16^{ab}
March	0.0253±0.0002^{b}	27.4±0.43^{b}	1.65±0.16b^{c}	0.22±0.04^{b}	0.84±0.17^{b}
April	0.0245±0.0006^{b}	28.3±0.50^{b}	1.61±0.15^{c}	0.22±0.05^{b}	0.82±0.13^{b}
May	0.0249±0.0004^{b}	27.8±0.66^{b}	1.59±0.17^{c}	0.21±0.03^{b}	0.81±0.12^{b}
June	0.0258±0.0003^{b}	26.9±0.80^{ab}	1.59±0.14^{c}	0.21±0.02^{b}	0.81±0.14^{b}
Mean	0.027 A	25.9 A	2.01 B	0.27 C	1.03 B
Flemingia macrophylla					
Initial	0		3.35±0.18	0.68±0.07	1.46±0.15
December	0.0291±0.0005^{b}	23.8±2.00^{ab}	1.95±0.16^{a}	0.40±0.05^{a}	0.85±0.13^{a}
January	0.0338±0.0006^{a}	20.5±0.80^{a}	1.69±0.14^{b}	0.34±0.06^{ab}	0.74±0.16^{ab}
February	0.0286±0.0004^{b}	24.2±0.60^{b}	1.56±0.17^{bc}	0.32±0.04^{b}	0.68±0.14^{b}
March	0.0267±0.0003^{c}	26.0±0.70^{bc}	1.50±0.13^{bc}	0.30±0.05^{b}	0.65±0.16^{b}
April	0.0255±0.0002^{c}	27.2±0.80^{b}	1.47±0.14^{c}	0.30±0.06^{b}	0.64±0.17^{b}
May	0.0262±0.0005^{bc}	26.5±0.90^{c}	1.46±0.17^{c}	0.30±0.07^{b}	0.63±0.14^{b}
June	0.0269±0.0006^{bc}	25.8±0.80^{bc}	1.45±0.16^{c}	0.29±0.06^{b}	0.63±0.16^{b}
Mean	0.028 A	24.9 A	1.80 C	0.37 B	0.79 C
Indigofera tinctoria					
Initial	0		4.12±0.22	0.98±0.09	1.88±0.16
December	0.0289±0.0007^{b}	24.0±2.00^{a}	2.39±0.19	0.57±0.07^{a}	1.09±0.14
January	0.0333±0.0006^{a}	20.8±0.90	2.06±0.18	0.49±0.06^{ab}	0.94±0.16^{a}
February	0.0279±0.0005^{b}	24.8±0.80^{ab}	1.90±0.21^{a}	0.45±0.05^{b}	0.86±0.15^{ab}
March	0.0258±0.0004^{bc}	26.9±0.70^{b}	1.81±0.22^{ab}	0.43±0.06^{b}	0.83±0.16^{ab}
April	0.0249±0.0003^{c}	27.8±0.60^{b}	1.77±0.23^{b}	0.42±0.07^{b}	0.81±0.17^{ab}
May	0.0254±0.0008^{bc}	27.3±0.70^{b}	1.75±0.18^{b}	0.42±0.08^{b}	0.80±0.13^{ab}
June	0.0258±0.0005^{bc}	26.9±0.90^{b}	1.74±0.22^{b}	0.41±0.06^{b}	0.79±0.14^{b}
Mean	0.027 A	25.5 A	2.19 A	0.52 A	1.00 B

Continue...

Period (month)	Decay rate (g day^{-1})	Half life (days)	Concentration of litter-N at sampling time (%)	Concentration of litter-P at sampling time (%)	Concentration of litter-K at sampling time (%)
Desmodium rensonii					
Initial	0		3.96±0.17	0.72±0.06	1.76±0.17
December	0.0289±0.0005^{bc}	24.0±0.70^{ab}	2.29±0.16^{a}	0.42±0.05^{a}	1.02±0.16^{a}
January	0.0326±0.0004^{c}	21.3±0.60^{a}	1.97±0.18^{ab}	0.36±0.06^{ab}	0.88±0.15^{ab}
February	0.0274±0.0003^{b}	25.3±0.50^{ab}	1.80±0.16^{ab}	0.33±0.07^{ab}	0.80±0.14^{bc}
March	0.0255±0.0004^{ab}	27.2±0.30^{c}	1.72±0.17^{bc}	0.31±0.06^{b}	0.76±0.13^{bc}
April	0.0248±0.0005^{a}	27.9±0.70^{c}	1.68±0.15^{bc}	0.30±0.05^{b}	0.74±0.12^{bc}
May	0.0251±0.0006^{a}	27.6±0.60^{c}	1.66±0.17^{bc}	0.30±0.06^{b}	0.74±0.14^{bc}
June	0.0264±0.0005^{b}	26.3±0.80^{bc}	1.65±0.16^{c}	0.30±0.07^{b}	0.73±0.16^{c}
Mean	0.027 B	25.7 A	2.09 AB	0.38 B	0.93 B
Cajanus cajan					
Initial	0		3.42±0.15	0.88±0.17	1.64±0.14
December	0.0325±0.0004^{c}	21.3±0.70^{ac}	2.13±0.16^{b}	0.55±0.06^{a}	1.43±0.13^{a}
January	0.0344±0.0005^{c}	20.1±0.60^{a}	1.86±0.17^{b}	0.48±0.07^{ab}	1.32±0.12^{ab}
February	0.0283±0.0006^{b}	24.5±0.50^{c}	1.72±0.18^{c}	0.44±0.06^{ab}	1.25±0.15^{bc}
March	0.0245±0.0007^{a}	28.3±0.60^{b}	1.63±0.12^{c}	0.42±0.05^{b}	1.22±0.16^{bc}
April	0.0242±0.0006^{a}	28.6±0.70^{b}	1.58±0.13^{c}	0.41±0.06^{b}	1.20±0.17^{bc}
May	0.0238±0.0005^{a}	29.1±0.60^{b}	1.56±0.12^{c}	0.40±0.04^{b}	1.19±0.15^{bc}
June	0.0248±0.0006^{a}	27.9±0.70^{b}	1.55±0.11^{c}	0.40±0.05^{b}	1.10±0.11^{c}
Mean	0.028 A	25.7 A	1.93 B	0.50 A	1.30 A

For each species, means followed by the same letter within a column are not significantly (p<0.05) different. Mean values with different uppercase letters within a column are significantly different at p<0.05.

Table 5: Nutrient contents in decomposing leaf litter of different multipurpose tree species, Eastern Himalaya, India

Period (month)	Decay rate (g day^{-1})	Half life (days)	Concentration of litter-N at sampling time (%)	Concentration of litter-P at sampling time (%)	Concentration of litter-K at sampling time (%)
Alnus nepalensis					
Initial	0	-	2.12±0.16	0.11±0.01	0.82±0.09
December	0.0072±0.0004^{a}	96.3±8.80^{c}	0.41±0.15^{b}	0.021±0.002^{a}	0.16±0.07^{a}
January	0.0182±0.0003^{a}	38.1±0.90^{bc}	0.27±0.14^{a}	0.014±0.003^{ab}	0.11±0.08^{a}
February	0.0309±0.0004^{a}	22.4±0.60^{a}	0.26±0.13^{a}	0.013±0.001^{b}	0.10±0.09^{a}
March	0.0253±0.0004^{a}	27.4±0.70^{a}	0.24±0.17^{a}	0.013±0.001^{b}	0.09±0.08^{a}
April	0.0224±0.0003^{a}	30.9±0.90^{ab}	0.24±0.16^{a}	0.012±0.001^{b}	0.09±0.06^{a}
May	0.0204±0.0002^{a}	34.0±0.80^{b}	0.23±0.15^{a}	0.012±0.002^{b}	0.09±0.07^{a}
June	0.0209±0.0003^{a}	33.2±0.70^{b}	0.23±0.14^{a}	0.012±0.004^{b}	0.09±0.06^{a}
Mean	0.021 AB	40.3 A	0.50 A	0.03 A	0.19 A
Chukrasia tabularis					
Initial	0	-	1.80±0.13	0.06±0.01	0.74±0.08
December	0.0071±0.0001^{a}	97.6±7.50^{a}	0.35±0.14^{a}	0.0115±0.0001^{b}	0.14±0.09^{a}
January	0.0191±0.0002^{a}	36.3±0.90^{b}	0.24±0.13^{ab}	0.0079±0.0001^{a}	0.10±0.08^{a}
February	0.0321±0.0003^{a}	21.6±0.70^{d}	0.22±0.12b	0.0074±0.0001^{a}	0.09±0.06^{a}

Continue...

Period (month)	Decay rate (g day^{-1})	Half life (days)	Concentration of litter-N at sampling time (%)	Concentration of litter-P at sampling time (%)	Concentration of litter-K at sampling time (%)
March	0.0272±0.0002[a]	25.5±0.80[c]	0.21±0.11[b]	0.0071±0.0001[a]	0.09±0.03[a]
April	0.024±0.0003[a]	28.9±0.80[c]	0.21±0.12[b]	0.0070±0.0001[a]	0.09±0.06[a]
May	0.0232±0.0001[a]	29.9±0.80[c]	0.21±0.15[b]	0.0068±0.0002[a]	0.08±0.06[a]
June	0.024±0.0002[a]	28.9±0.90[c]	0.20±0.16[b]	0.0068±0.0003[a]	0.08±0.05[a]
Mean	0.022 A	38.4 B	0.43 B	0.01 C	0.18 A
Gmelina arborea					
Initial	0		1.40±0.12	0.04±0.001	0.55±0.07
December	0.0084±0.0001	82.5±9.50	0.31±0.11[a]	0.0089±0.001[a]	0.11±0.06[a]
January	0.023±0.0002[a]	30.1±0.83[ab]	0.23±0.12[ab]	0.0066±0.002[a]	0.07±0.05[a]
February	0.0345±0.0003	20.1±0.90	0.22±0.13[b]	0.0063±0.001[a]	0.07±0.03[a]
March	0.0283±0.0004	24.5±0.82	0.21±0.16[b]	0.0061±0.001[a]	0.06±0.01[a]
April	0.0244±0.0005[a]	28.4±0.95[a]	0.21±0.16[b]	0.0060±0.001[a]	0.06±0.02[a]
May	0.0224±0.0004[a]	30.9±0.81[b]	0.21±0.17[b]	0.0059±0.001[a]	0.06±0.01[a]
June	0.022±0.0002[a]	31.5±0.96[b]	0.20±0.11[b]	0.0058±0.002[a]	0.06±0.01[a]
Mean	0.023 A	35.4 B	0.37 C	0.01 C	0.13 B
Michelia champaca					
Initial	0	-	1.60±0.10	0.08±0.01	0.62±0.06
December	0.0066±0.0001[e]	105.0±8.25[a]	0.29±0.08[a]	0.0143±0.002[a]	0.11±0.05[a]
January	0.0172±0.0002[d]	40.3±1.54[b]	0.18±0.04[ab]	0.0092±0.001[b]	0.07±0.03[a]
February	0.0299±0.0003[a]	23.2±0.80[e]	0.17±0.03[b]	0.0086±0.001[bc]	0.07±0.03[a]
March	0.0243±0.0004[b]	28.5±0.91[d]	0.16±0.04[b]	0.0081±0.002[c]	0.06±0.02[a]
April	0.021±0.0001b[c]	33.0±0.83[c]	0.16±0.05[b]	0.0078±0.001[c]	0.06±0.01[a]
May	0.0189±0.0002[c]	36.7±0.96[c]	0.15±0.02[b]	0.0075±0.002[c]	0.06±0.02[a]
June	0.0197±0.0002[c]	35.2±0.80[c]	0.15±0.04[b]	0.0074±0.001[c]	0.06±0.01[a]
Mean	0.020 B	43.1 A	0.36 C	0.02 B	0.14 B

For each species, means followed by the same letter within a column are not significantly ($p<0.05$) different. Mean values with different uppercase letters within a column are significantly different at ($p<0.05$)

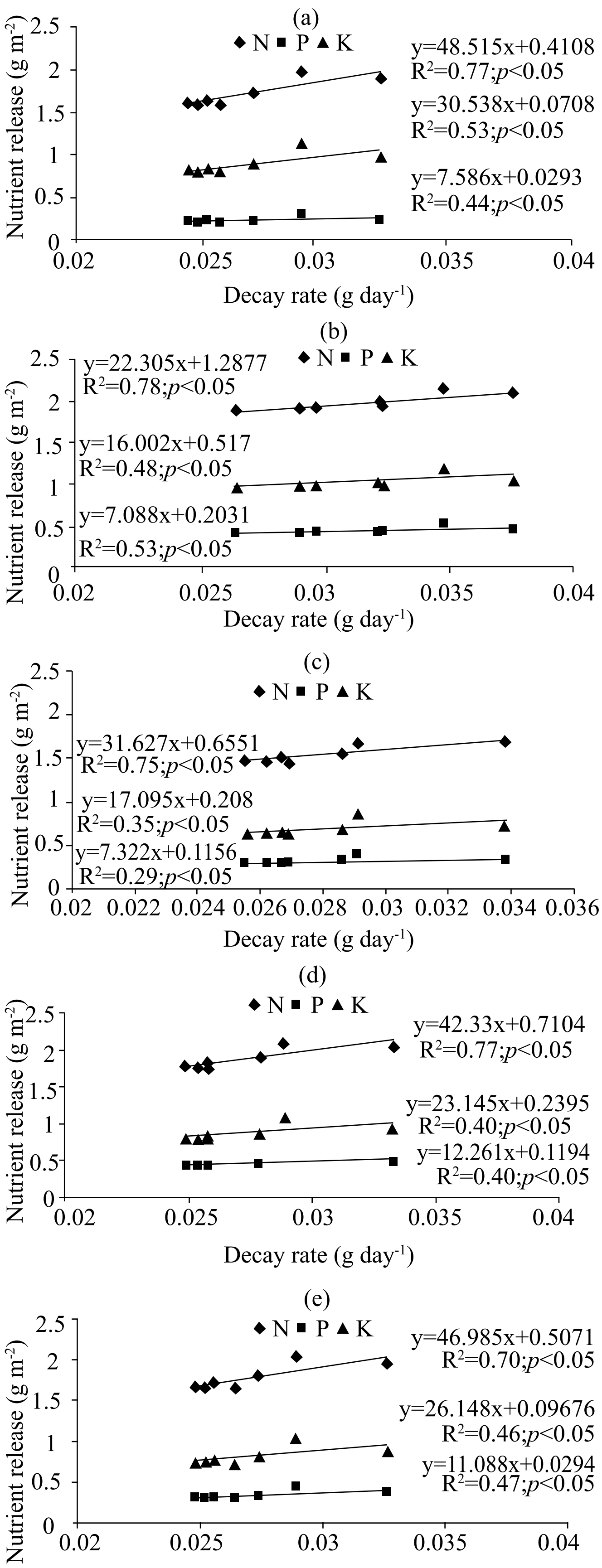
Table 6: Regression relationship between N release and decay rates (g day^{-1}) of hedges and multipurpose trees (MPTs)

Species	Observed equation	SE	R^2
Crotolaria tetragona	y=46.98x+0.5071	0.0023	0.70**
Tephrosia candida	y=42.052x+0.5621	0.0016	0.74**
Flemingia macrophylla	y=22.305x+1.28	0.0015	0.77**
Indigofera tinctoria	y=48.51x+0.41	0.0015	0.76**
Desmodium rensonii	y=31.62x+0.65	0.0023	0.74**
Cajanus cajan	y=42.33x+0.71	0.0019	0.77**

** indicates significant at $p<0.01$

the reason of negative correlation. For our observation we made decay rates as the independent variable and nutrient release as the dependent. We then obtained more clustering of the points for hedges and more scattering for the MPTs for all three nutrients. Since regression coefficients could not significantly explain the variances obtained for P and K release due to same R^2 value of 0.5, there may be several other factors associated with the explanation of this phenomenon. Several researchers (Budelman, 1988) earlier obtained linear relationship between K release and decay rate by inverse relationship of decomposition equation as:

$R(t)=(D\times P)\times(1- e^{-kt})$ in which R (t) represents the amount of a specific nutrient released in kg ha^{-1} after a certain period of time (t) in days, D is the dry mulch matter initially applied in kg ha^{-1}. P is the presence of the nutrient in the mulch material as a fraction.



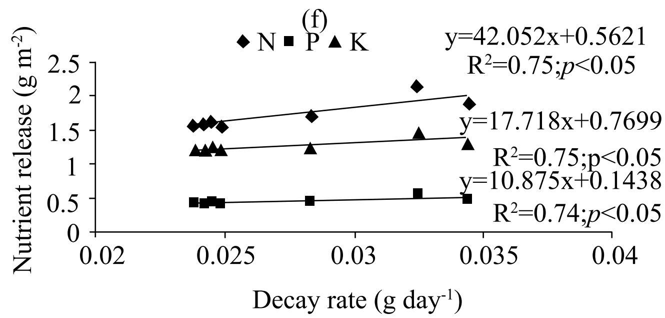


Figure 5: Regression curves for nutrient release (g m^{-2}) over decay rates (g day^{-1}) for (a) *Crotolaria tetragon*, (b)*Tephrosia candida*; (c) *Flemingia macrophylla*, (d) *Indigofera tinctoria*, (e) *Desmodium rensonii* and (f) *Cajanus cajan* during the study period

Table 7: Prediction of N release and decay rates (g day^{-1}) of hedges and MPTs in relation to measured N from the regression equation

Species	Predicted N	Measured N	Correlation
Crotolaria tetragona	2.01	2.37	0.72^{**}
	2.12	2.12	
	2.00	2	
	1.94	1.94	
	2.00	1.93	
	1.93	1.92	
	1.87	1.91	
Tephrosia candida	1.82	2.22	0.72^{**}
	1.97	1.9	
	1.72	1.74	
	1.63	1.65	
	1.59	1.61	
	1.61	1.59	
	1.66	1.59	
Flemingia macrophylla	1.57	1.95	0.57^{*}
	1.72	1.69	
	1.55	1.56	
	1.499	1.5	
	1.46	1.47	
	1.48	1.46	
	1.50	1.45	
Indigofera tinctoria	1.93	2.39	0.64^{**}
	2.11	2.06	
	1.80	1.9	
	1.76	1.81	
	1.78	1.77	
	1.80	1.75	
	1.22	1.74	

Continue...

Species	Predicted N	Measured N	Correlation
Desmodium rensonii	1.86	2.29	0.66**
	2.00	1.97	
	1.79	1.8	
	1.70	1.72	
	1.67	1.68	
	1.68	1.66	
	1.74	1.65	
Cajanus cajan	1.92	2.13	0.86**
	2.00	1.86	
	1.75	1.72	
	1.59	1.63	
	1.56	1.58	
	1.60	1.56	
	1.47	1.55	

** indicates significant at $p<0.01$

4. Conclusion

Extremely rapid decomposition rate underscores the utility of hedgerows leaf mulch as efficient nutrient enricher as well as organic plant nutrient supplement. The decay rate was significantly ($p<0.05$) positively correlated with nutrient release in case of hedges and negatively correlated in case of MPTs. Significant positive correlation was also found for predicted N release in relation to decay rates over measured N in case of hedges. Thus, adoption of hedges is recommended for better nutrient cycling in the Indian sub-Himalayas.

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