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Litterfall, Decomposition and Nutrient Dynamics in Traditional Agro-Forestry Systems of Northeast India

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ABSTRACT

We investigated litter production, litter decomposition and nutrient dynamics from three traditional agroforestry systems in Harmutty (Assam) and Nirjuli and Doimukh (Arunachal Pradesh) in northeast India. Litter production was studied by using litter traps and decomposition of leaf litter by nylon net bag technique. On an average, litterfall was 1406 kg ha^{-1} yr^{-1} that was influenced by climatic variables. Canopy species such as *Areca catechu* and *Gmelina arborea* accounted for about 30% of the total litter production. Analysis of variance indicated significant difference at 0.05 level in leaf and non-leaf litter (F=16.25; P=2.96). Overall, leaf litterfall was greater during winter in Harmutty and Doimukh sites and during autumn in Nirjuli site. This is attributed to species characteristics. The litter biomass on the floor of different agroforestry sites varied from 455 to 755 kg ha^{-1}. Trees provide about 75% of the total leaf litterfall; *Areca catechu* contributed 13%, followed by *Alstonia scholaris* (3.8%). Altogether, shrub species contributed 24% of the litter. Decay rate was highest for *Colocasia esculenta* (8.61) and lowest in *Livistona jenkinsiana* (0.68). The initial N content was greater in *Ageratum conyzoides* and lower in *Musa* sp. During the early period of decomposition nutrients decreased whereas the concentration of nitrogen increased. The residue quality could contribute to the nutrient cycling processes that facilitates the production and productivity of agroforestry systems *per se*.

Key Words: Agroforestry; Decomposition; Littefall; Nutrient Dynamics; Northeast India

INTRODUCTION

Agroforestry is an ideal scientific approach for eco-restoration of degraded lands and sustainable resource management (Tripathi et al. 2009), in which litterfall and litter decomposition and subsequent nutrient release represent major biological pathways for element transfer from vegetation to soils, and play an important role in regulating nutrient cycling, and in maintaining soil fertility in forest and agro-ecosystems (Dawoe et al. 2010, Triadiati et al. 2011). Litter accumulation on the topsoil depends on several factors i.e. plant species, climate, land use types, decomposers population and their activities (Fernandes et al. 1997) and their decomposition process is influenced by a number of factors such as microclimate, mainly temperature and humidity, litter quality, soil nutrient content and the qualitative and quantitative compositions of decomposer communities (Anderson and Swift 1983, Dawoe et al. 2010). The choice of the tree species for plantation forestry or agroforestry is influenced by knowledge of the species performance and their economic and environmental benefits.

It is understood that quality or the initial chemical characteristics of litter played great role in the process of decomposition (Swift et al. 1979). Nevertheless, the decomposition of litter in agroforestry system differs from that of in the natural forest and in the agricultural system, because of differences in the types and quality of organic inputs (Mafongoya et al. 1998). A balance between litter deposition and decomposition regulates the accumulation of organic matter within an ecosystem (Singh et al. 2004). Over all, the product of litterfall decomposition is facilitating the formation of soil organic matter and return nutrient into soil (Odiwe and Muoghalu 2003, Xuluc-Tolosa et al. 2003).

Despite many studies carried out on litterfall and decomposition dynamics, in both tropical and temperate forests and agroforests (Berg 2000, Ranger et al. 2003, Martius et al. 2004, Isaac et al. 2005), no study has been made on the decomposition of litter components in traditional homestead agroforestry species in Arunachal Pradesh. Understanding the nutrient dynamics of litter in these ecosystems is critical to advise small farmers who depend on natural nutrient recycling for fertility sustenance. This paper discusses litter dynamics to with reference to decomposition and nutrient cycling patterns in traditional agroforestry systems in and around Arunachal Pradesh, northeast India.

MATERIALS AND METHODS

Site Description

The field study was conducted during November 2002 to October 2003 on small-holder traditional homestead agroforestry farms in Harmutty (North Lakhimpur district, Assam) and Nirjuli and Doimukh (Papum Pare district, 126 m above mean sea level), Arunachal Pradesh (120 m above mean sea level, 14 km from the site in Assam), northeast India. Harmutty site (I) was inhabited by the Kalita group of Assam whilst Nirjuli (II) and Doimukh (III) were inhabited by the Nyishis, one of the major tribes of Arunachal Pradesh. These areas receive most rainfall (ca. 80%) during summer months (May-July) with relatively a little or none during winter (November-January). The area experience a humid tropical climate with total annual rainfall (typically 1100-1600 mm) and average daytime temperatures vary from a minimum of 12^{o} C to a maximum of 37^{o} C. Geologically, the parent rock exposed around Doimukh and Nirjuli area consists of newer alluvium (newer terrace deposits) represented by valley field deposits, mainly the sediments. In Harmutty, the alluvium belongs to Pleistocene and recent times (Kumar 1997).

Litter Production

Ten litter traps of 1m ×1m each were randomly placed in 20 subplots in each agroforestry sites to determine tree litter production. The accumulated litter in each trap was collected at monthly intervals for a period of one year. The litter samples were brought to the laboratory and separated into leaf litter, woody litter and miscellaneous litter (flowers and fruits, bark, unrecognizable remains of leaves and fine particles) fractions. The samples were dried at 80°C temperature and weight and result has been presented on dry weight basis. Initial leaf litter carbon, nitrogen and phosphorus concentrations were determined (Allen et al. 1974, Anderson and Ingram 1993). Major cell wall constituents (lignin, cellulose and hemi-cellulose) were determined from their concentration in the remaining litter of the decomposed sample (Peach and Tracey 1956). Percentage nutrient remaining was calculated as:

$$\text{Nutrient remaining (\%)} = (C/C_0) \times (DM/DM_0) \times 10^2),$$

where C is the concentration of each element in the leaf litter at the time of sampling, C_0 is the concentration of initial litter kept for decomposition, DM is the mass of dry matter at the time of sampling, DM_0 is the initial dry matter of the litter sample kept for decomposition (Bockheim et al. 1991).

Litter Decomposition

Litter decomposition was studied following nylon-bag technique (Gilbert and Bocock 1960). Nylon mesh (2 mm) litterbags (10 cm x 15 cm) were used to study litter decomposition and nutrient dynamics of leaf litter under field condition. Fresh leaf litter was collected, processed, separated and air-dried. Oven-dry weight (48 hr, 80°C) of litter was also determined using a sub sample. Thirty gram air-dried leaf litter sample was kept in each litter bag. Sufficient numbers of litter bags were placed in each agroforestry system (under the soil surface to enable replicate samples at monthly intervals. On each sampling day, 4 litter bags of each species were retrieved and brought to the laboratory for analysis. The bags were washed under gentle flow of tap water to remove soil particles, fine roots and living organisms adhering on litter and then dried at 80°C for 24 h. The dry weight of litter was taken and then powdered for N and P. Nitrogen was determined by micro-Kjeldahl digestion-distillation method and phosphorus by molybdenum blue method (Allen et al. 1974, Anderson and Ingram 1993). Dry weight loss and nutrient release from the decaying litter was computed according to Singh et al. (1999) and Guo and Sims (1999).The net organic matter decay was computed using 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 is the base of natural logarithm, k is the decay rate coefficient and t is the time (year). The time required to achieve 50% (t_{50}) and 99% (t_{99}) decay was calculated as t_{50} =0.693/k and t_{99} =5/k. Monthly weight loss (g month^{-1}) from decomposing litter was determined from the difference between the mass remaining in the litterbags in each month and the initial fresh weight.

To estimate the floor-litter biomass, 1 m^2 quadrat was randomly placed twice a year on each plot and all the materials inside the quadrat were removed. The materials were separated in the same manner as for litterfall and dried at 105°C. Total N was estimated from the litter by using Pelican semi-automatic N analyser. The NUE (nitrogen use efficiency) was calculated using Vitousek's (1984) practical definition of NUE, which is the ratio of the dry matter: nitrogen content of litter fall, or the inverse of litter N concentrations.

The data collected from each of the three sites were analyzed using ANOVA to test the significance level of variations due to different depth and sites. Linear regressions were also used where necessary, according to Zar (1974).

RESULTS AND DISCUSSION

Total Litterfall

Litter production is a major process by which carbon and nutrients are transferred from vegetation to soil (Dawoe et al. 2010). A mean total of 1406 kg ha^{-1}yr^{-1} of litterfall dry weight has been estimated (Table 1) from three different traditional agroforestry sites. Out of the total litter contents leaves were the preponderant fraction (27.4 to 87.1%), while miscellaneous fractions (7.63-39.9%) and twigs (0.79-49.5%) did contribute to total litterfall. Nonetheless, the values of litterfall in these systems were much lower than in the other forest ecosystems studied around the world. The litterfall production in lowland evergreen tropical rainforests around the world ranges from 5700 kg ha^{-1}yr^{-1} in a heath forest in Venezuela to 12400 kg ha^{-1}yr^{-1} in Zaire (Proctor 1984). In this study, litter production was highest (278 kg ha^{-1}) in the month of November which may perhaps be owing to higher leaf fall during the dry season and windy conditions in the sites as climate is the primary determinant of litter production (Facelli and Pickett 1991).

Table 1. Total litter fall, litter biomass, mean residence times (the inverse of litter fall: floor mass= 1/ K_L) , litter fall N and nitrogen use efficiency for litter

Site	Litter fall (kg ha^{-1})	Litter biomass (kg ha^{-1})	1/ K_L (Yr)	Litter fall N %	NUE (kg ha^{-1})
I	1372	773.67	0.56	14.68	93.46
II	1380	640.33	0.46	14.76	93.49
III	1468	454.67	0.31	15.70	93.50

Most litterfall studies in tropical forests have demonstrated a strong seasonality of leaf litterfall, with the peak in the dry season (Wieder and Wright 1995, Lawrence and Foster 2002). It has also been reported that litterfall may be affected by physical factors such as the mechanic action of wind and rain or physiological responses of the plants to environment changes (ICP Forests 2004, Santiago and Mulkey 2005). Nonetheless, rarely, peak litterfall has also been reported during wet season in Zaire (Laudelout and Meyer 1954) and New Guinea (Edwards 1977). Analysis of variance indicated significant difference at 0.05 level in leaf and non-leaf litter (F=16.25, P= 2.96).

Figures 1 and 2 show the relationships between different litterfall components and climate; 56.52% of the annual litter production occurred during dry periods

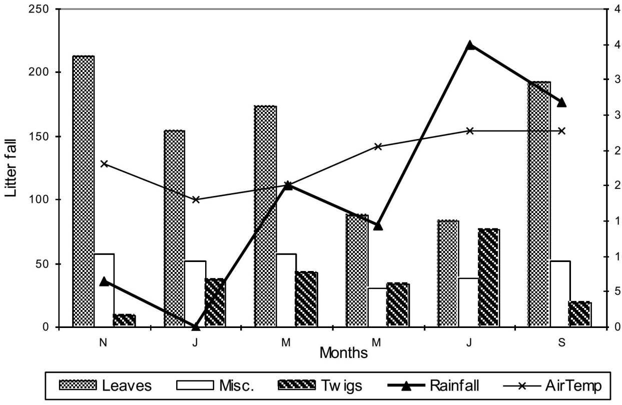

Figure 1. Litter fall (kg ha^{-1}) pattern in relation to climatic variables

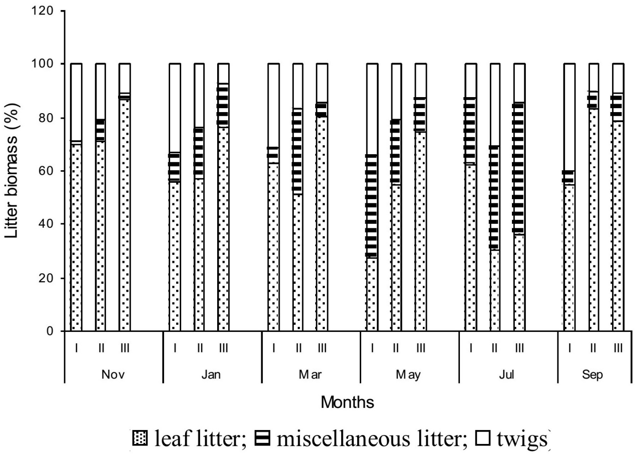

Figure 2. Contribution of different litter components to total litter

(November to March). Woody and miscellaneous litter fraction had their peak production in July (rainy season) that may have been due to wind-storm during monsoon, which also dislodged small woods, fruits and miscellaneous fractions from the standing biomass. Nevertheless, the pattern of miscellaneous and woody litterfall during the study period was not consistent, and was prone to vary by several months. Total leaf litterfall was greater in Nirjuli, partly due to pronounced dry season and partly due to presence of more deciduous trees, which senesced leaves and fruits after a certain period of time. Several studies including e.g. (Wieder and Wright 1995, Lian and Zhang 1998, Yang et al. 2003, Dawoe et al. 2010) have reported that the seasonal pattern of litterfall largely depended on the factors responsible for leaf senescence and abscission. Carabias and Guevara (1985) showed an apparent relationship between litterfall and the yearly weather pattern. But this relation was not being statistically significant in this study owing to the non-independent and non-random nature of the phenological events as well as the anthropogenic activities and disturbances in the systems were also very frequent. Miscellaneous litter fractions were also collected more in winter to rest of seasons, twig fall was highest in rainy and autumn seasons in all the sites. Litterfall pattern of trees could be attributed to differing physiological response to water stress and leaf longevity. In the present study, about 44.33% of leaf litterfall occurred during winter months, whereas summer season accounted for 33.86% of total annual litterfall. Litterfall addition during rainy season was only 21.77%. However, the fall of miscellaneous litter was very irregular in time and space. Twigs litter was more conspicuous during September-January. Overall, the seasonal pattern of leaf litterfall showed a maximum during winter in Harmutty and Doimukh sites (Figure 3) because of prolonged dry period, whereas it was more in Nirjuli site during the autumn possibly due to the species characteristics.

Litter Biomass Accumulation and Turnover

The litter biomass on the floor of different agroforestry sites varied from 455 to 755 kg ha^{-1}. Though the litter biomass was more in Harmutty, litterfall was lower than other two sites which may be due to more intractable herbaceous litter components. On the other hand, presence of more deciduous trees in Doimukh site leads to the production of more leaf litterfall. Miscellaneous litter was also highest at the Harmutty site. The mean

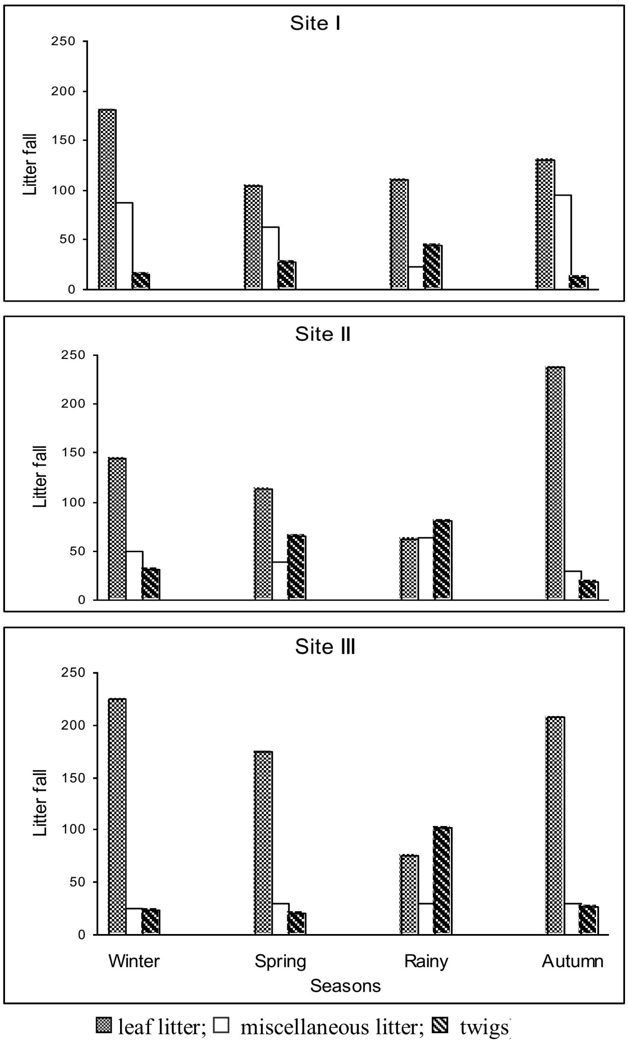

Figure 3. Seasonal dynamics of litter (kg ha^{-1}) in traditional agroforestry systems.

residence time of litterfall ranged from 0.31-0.56 years, with the maximum at the Harmutty site and the lowest at the Doimukh site (Table 1), which indicates that the aboveground litter, particularly leaf and branch litter of trees in the present system were relatively recalcitrant in Harmutty. The turnover rate of litter in the present study corroborates that reported in several tropical and sub-tropical evergreen and deciduous forests (Vogt et al. 1986). The turnover quotient below one is infrequent in tropical lowland forests, because litter decomposition is accelerated by warm temperature and higher moisture conditions (Anderson and Swift 1983).

Leaf Litterfall by Species

Litter production varies according to habit of the tree species, its age and local environmental condition (Szott and Kass 1993). Data on litter production indicates that major portion was contributed by leaf and several other workers reported similar findings from different forest stands (Sanchez and Sanchez 1995, Sundarpandian and Swamy 1999, Zhou et al. 2007). The litter standing crop represents the balance between input by litterfall and output by decomposition (Tripathi et al. 2009). *Areca catechu* and *Gmelina arborea* accounted for 30.49% of the total litterfall. *Areca catechu* contributed 13.17%, followed by *Alstonia scholaris* (3.78%). Altogether, shrubs contributed 23.93%. Bray and Gorham (1964) reported that the amount and pattern of litterfall varies with the type of species, their growth pattern and age, density and canopy characteristics. The five most important species providing the highest litterfall per month were *Areca catechu* (118.95 kg ha^{-1}), *Gmelina arborea* (155.42 kg ha^{-1}), *Livistona jenkinsiana* (96.68 kg ha^{-1}), *Bambusa tulda* (48.32 kg ha^{-1}) and *Musa* sp. (154.59 kg ha^{-1}).

The leaf fall contributed highest biomass (64.22%). Trees provide 76.06% of the total leaf litter-fall (Table 2). Concerning the trees, upper layer species (>20m) represents 54.60% of the leaf litterfall mass, middle layer species (10-20m) represented 46.35%, and understorey species (0-10m) 4.40%. Earlier, Burghout (1993) found correlation between leaf litterfall and basal area, and tree density at a family level in Malaysia. The canopy layer species show more litterfall than the lower canopy species indicating that the harvesting of many small trees would seem to be better than few large trees.

Phenology of the same species varies greatly among sites. Interestingly, the same species showed different pattern of litterfall in different sites. Cycles of leaf renewal can be of variable length and are not necessarily synchronized among individuals, such that species ranking in litterfall production changes easily among annual periods and sites. Litterfall seasonality appears more consistent at the community level than the species level. This is exemplified by Carabias and Guevara (1985) who found a consistency in seasonal pattern of community leaf and flower shedding during five years in Los Tuxtlas.

Table 2. Contribution of leaf litter (LL; % dry weight) by families in traditional agroforestry systems.

Family	%LL	Species	Family	%LL	Species
Arecaceae	23.87	2	Moringaceae	2.153	1
Moraceae	4.413	1	Apocynaceae	34.15	1
Bignoniaceae	0.687	1	Dilleniaceae	4.00	1
Caesalpinaceae	1.632	2	Anacaedaceae	6.874	1
Clusaceae	1.808	1	Rubiaceae	1.688	1
Mrytaceae	0.582	1	Palmeae	3.252	1
Thymelaceae	0.203	1	Proteaceae	1.510	1
Fabaceae	0.825	1	Meliaceae	4.432	1
Leguminoseae	0.078	1	Verbanaceae	17.20	1
Euphorbiaceae	0.197	1	Lythraceae	0.196	1
Combretaceae	0.365	1	Poaceae	5.349	1
Musaceae	17.11	1	Rutaceae	0.444	1
Caricaceae	0.196	1	Sonneratiaceae	0.196	1

Litter Decomposition

The decomposition of leaf litter is largely influenced by the concentrations and ratios of nutrients (Berg and McClaugherty 2008). A comprehensive knowledge of the organic matter decomposition and nutrient release patterns from leaf litter maximizes soil sustainability and crop productivity (Mugendi et al. 1999). In the present study, the values pertaining to the periodical disappearance of the litter indicated that the total mass loss increased with increase in time but the monthly mass loss was not uniform over different months. The slow process of decomposition observed during the initial February-March months might be due to the low moisture content during that time and hence low microbial population.

The weight loss pattern of some selected species is presented in Figure 4. At the end of the first month the percentage of initial mass remaining in the litterbags was maximum (99.6%) for *Livistona jenkinsiana*, followed by *Artocarpus heterophyllus* (93.5%). The soil moisture

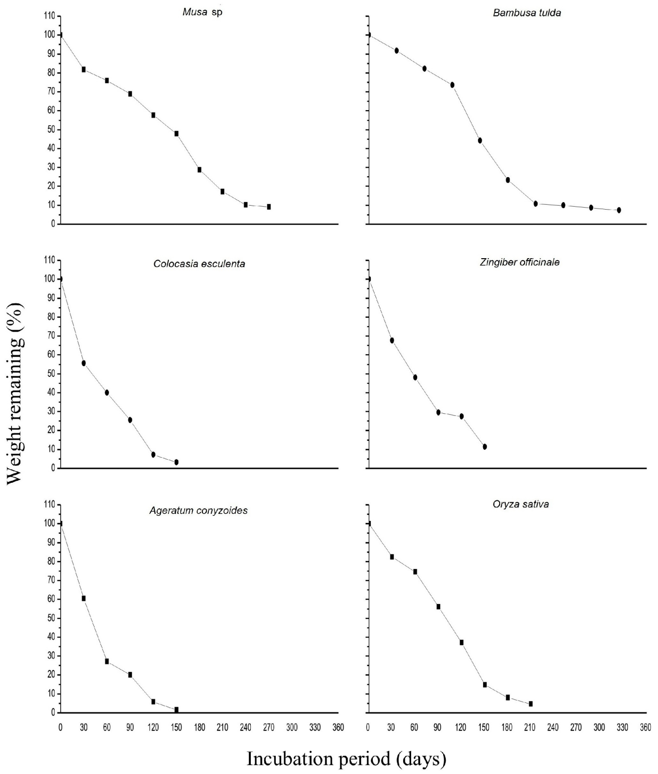

Figure 4a. Decay rate of the dominant traditional agroforestry species

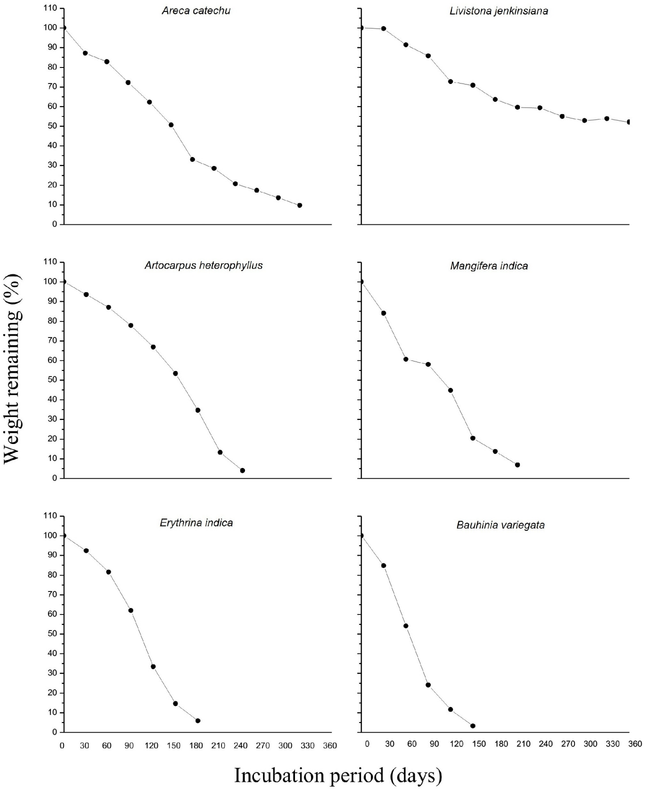

Figure 4b. Decay rate of the dominant traditional agroforestry species

content increased from February to July and again decreased in November. Since climate of the study site was humid subtropical with distinct wet and dry seasons, litterfall and its decomposition was related to seasonal cycle. Leaf fall was more prominent during autumn and winter seasons. The minimum litter mass on the ground during rainy season is therefore attributed to rapid decomposition owing to greater microbial activity due to favourable temperature and moisture conditions.

With the onset of monsoon showers in June, there was a sudden uplift in the decaying process and consequent mass loss. Maximum disappearance of mass in most of the species was observed in July month. The reported studies indicated that temperature and moisture are critical environmental factors for high rates of decomposition. During the post-monsoon after the rapid loss of decomposable substances the relatively more resistant materials might have remained in the litter bags causing decrease of mass loss during the following months. Low rainfall might also be the factor for slow decomposition. So it can be seen from Figure 4 that most of the species revealed a biphasic model of decomposition with a rapid initial phase followed by a slow later phase. Heavy leaching losses of water soluble C fraction from the decomposing leaf biomass during the rainy period might have accounted for the heavy mass loss also have been observed by Kunhamu (1994) in his study using tropical agroforestry tree species.

Ageratum conyzoides, *Zingiber officinale*, *Colocasia esculenta* and *Bauhinia variegata* required minimum time of 150 days to attain 90% decomposition among the twelve species. Decomposition studies in traditional agroforestry systems by Bharadwaj et al. (1992) revealed a high mass loss for *Leucaena leucocephala* sp, *Eucalyptus* sp and *Prosopis juliflora* during 274 days of exposure of decomposition. Other studies have also reported linear decrease in weight on the litter decomposition process (Okeke and Omalika 1991). The decay rate constant (Table 3) of different species indicated the difference in the process of decomposition. Decay rate was highest for *Colocasia esculenta* (8.61) followed by *Bauhinia variegata* (8.38), whereas lowest decay rate was observed in *Livistona jenkensiana* (0.68), followed by *Areca catechu* (2.58). Consequently the half-life value of *Bauhinia* sp. and *Colocasia esculenta* were also lowest (0.08).

The higher relative loss during the rainy season compared to the dry season in this study might be due to

Table 3. Decay and nutrient constants in different agroforestry species.

Species	Weight decay			Nutrient decay		
	k	t_{50}	t_{99}	k_N	k_C	K_P
Areca catechu	2.58	0.27	1.94	0.63	1.02	4.32
Livistona jenkinsiana	0.68	1.01	7.30	0.57	0.75	1.85
Artocarpus heterophyllus	4.91	0.14	1.02	2.03	1.37	3.55
Mangifera indica	4.68	0.15	1.07	5.32	2.07	2.24
Erythrina indica	5.78	0.12	0.86	3.27	3.30	4.76
Bauhinia variegata	8.38	0.08	0.60	2.72	2.85	2.10
Musa sp	3.24	0.21	1.54	3.16	1.78	1.56
Bambusa tulda	3.52	0.19	1.42	1.28	0.38	5.74
Colocasia esculenta	8.61	0.08	0.58	7.50	3.47	3.69
Zingiber officinalis	5.34	0.13	0.94	4.45	3.76	3.87
Ageratum conyzoides	0.22	0.15	1.07	5.15	1.09	5.35
Oryza sativa	5.37	0.13	0.93	2.77	1.53	4.33

k= The decay rate coefficient, t_{50} = The time required to achieve 50% decay, t_{99}= The time required to achieve 99% decay, k_N= N mineralization constant, k_C= C mineralization constant, k_P= P mineralization constant

Table 4. Initial litter composition (%) in different agroforestry species.

	C	N	P	Lignin	Cellulose	Hemicellulose	C/N	C/P	Lignin/N
Areca catechu	40.77	1.26	0.17	29.15	16.45	7.33	32.36	239.82	23.13
Livistona jenkinsiana	42.78	0.45	0.05	37.20	11.50	5.12	95.07	855.60	82.67
Artocarpus heterophyllus	31.25	1.13	0.16	17.48	36.00	7.60	27.65	195.31	15.47
Mangifera indica	29.16	0.73	0.12	19.37	24.26	20.22	39.95	243.00	26.53
Erythrina indica	28.06	1.94	0.15	21.23	20.17	18.00	14.46	187.07	10.94
Bauhinia variegata	26.88	1.89	0.10	20.94	20.73	18.47	14.22	268.80	11.08
Musa sp	26.39	0.28	0.13	14.89	30.66	21.23	38.80	203.00	53.17
Bambusa tulda	28.52	1.02	0.09	24.51	22.00	6.02	27.96	316.89	24.03
Colocasia esculenta	23.45	1.39	0.11	13.23	21.48	14.60	16.87	213.18	9.52
Zingiber officinalis	25.51	0.89	0.06	13.81	31.00	17.33	28.66	425.17	15.52
Ageratum conyzoides	26.13	2.39	0.06	11.00	22.05	27.48	10.93	435.50	4.60
Oryza sativa	26.42	0.49	0.11	21.03	26.00	19.54	53.92	240.18	42.92

the effect of physical determinants of the rate of litter decomposition, particularly soil moisture content. In most of the species the rate of decomposition was positively correlated with soil moisture content. Very feeble correlation existed between weather variables such as monthly rainfall, mean temperature, relative humidity with rate of decomposition of various species. Moreover, heavy leaching losses of water soluble carbon fractions from the decomposing leaf biomass during the rainy season might have accounted for the heavy mass loss during the initial phase. Apart from the chemical factor, the faunal diversity and their decomposing ability influence the rate of decomposition. A high diversity of faunal groups, the majority having a significant role in the decomposing process was noted in this soil.

Nutrient Release Pattern

Decomposition of litterfall involves the chemical and physical processes that reduce litter to CO_2, water and mineral nutrients (Lambers et al. 1998).The initial N content was greater in *Ageratum conyzoides* and lower in *Musa* sp (Table 4). During decomposition of litter, the concentration and total nitrogen remaining (% N) in the

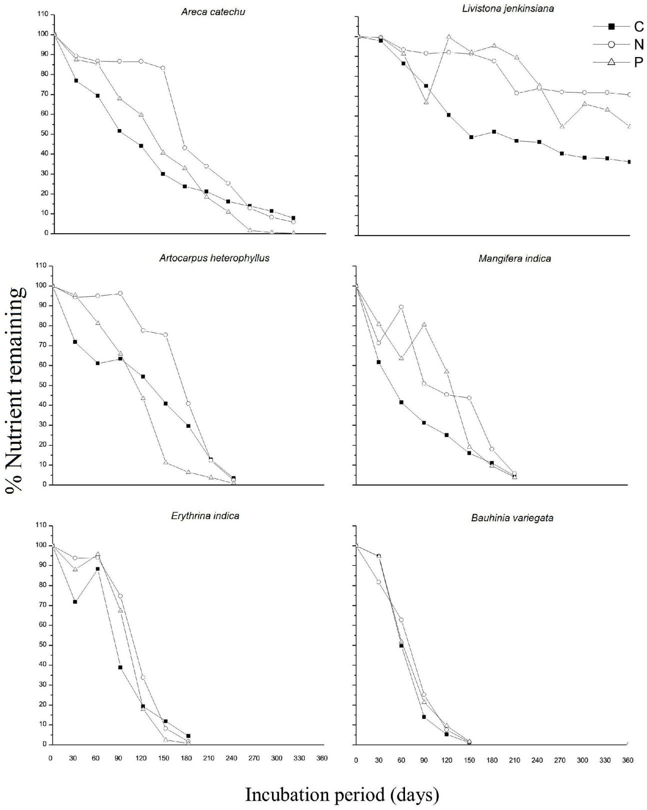

Figure 5a. Nutrient remaining (%) in different agroforestry species

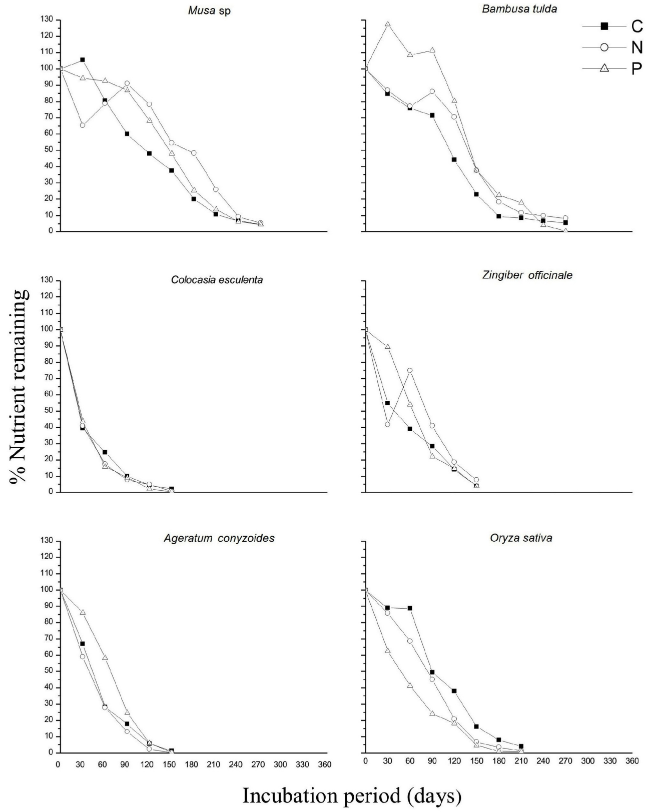

Figure 5b. Nutrient remaining (%) in different agroforestry species

decomposed sample showed variable trends. During the early period of decomposition the nutrient remaining decreased whereas the concentration of nitrogen increased (Figure 5a,b). This period can be considered as an accumulation phase and it continued up to September. This was almost certainly due to the intense immobilization activity of microbes including N-fixing ones during these most favorable climatic conditions coupled with the rapid decomposition of organic matter compared with the release of nitrogen. Increase in N concentration during rainy season indicated more nutrient immobilization. After September it again decreased and at the end of monsoon period, the content of N was reduced to 22-28% in *Musa* sp and *Areca catechu*, whereas it increased from 18-31% in *Bambusa tulda* and *Livistona jenkinsiana*. But some of the species like C*olocasia esculenta*, *Zingiber officinale* etc. decomposed before the end of monsoon period. The mean initial N concentration in the leaf litter of dominant species is 1.16% and varies from 0.28-2.39% among the 12 dominant species of studied agroforestry systems. *Bambusa tulda*, *Areca catechu*, *Livistona jenkinsiana*, *Artocarpus heterophyllus* were showing gradual N increase until the 5th month and then declined at the end of the decomposition. But all species was not showing the same trend, some of them decompose earlier whereas some other species like *Areca catechu* and *Livistona jenkinsiana* showing the opposite trend. The second phase of decrease in N content may be attributed to the mineralization of the element from the litter. The short term immobilization and final release observed in this study agreed to the report of Jamaludheen and Kumar (1999). The rapid rate of decay after an initial lag phase is the net effect of a large number of processes such as utilization of readily available energy sources by microbes and loss of water-soluble components from leaf litter (Bloomfield et al. 1993, Tripathi et al. 2009). In general, the decomposition rates increase with a decrease in the ratio of carbon to N (C:N ratio), which is therefore an important indicator of litter quality (e.g., Heal et al. 1997). Another constituent limiting the 19rate of litter degradation is lignin (Osono and Takeda 2005, Jacob et al. 2010), a complex aromatic hetero-polymer in cell walls, which is one of the litter components that are most recalcitrant to decomposition (Osono 2007, Berg and McClaugherty 2008). Therefore, not only the species mixture of the litter *per se* but also the presence or absence of individual litter species can influence the decomposition rate within a mixture.

Many researchers have developed predictors or indices of decomposition and nutrient release (Mtambanengwe and Kirchmann 1995, Mafongoya et al. 1997). These indices which include ratios of carbon to nitrogen (C:N), polyphenol to nitrogen (PP: N), lignin to nitrogen (L:N), and polyphenol+lignin to nitrogen ratios (PP+L: N) are all apparently valid, however other factors such as site conditions may also be important moderating factors (Anderson and Swift 1983, Mafongoya *et al.* 1998). Apart from climatic conditions, decomposition of plant residues is known to be influenced by edaphic factors (soil texture and bulk density), decomposer organisms and resource quality (i.e., ratio of C to N, lignin to N, and polyphenolics to N) (Tian et al. 1997, Hairiah et al. 2006). Apart from affecting the chemical composition of the soil, litter that is only slowly degradable builds up thicker layers of organic matter on the soil surface, which persist over longer periods of time. The structure of the organic surface layer, in turn, can affect the rates of litter decomposition as a result of the microclimatic conditions (Sayer 2006, Sariyildiz 2008).

The concentration and percentage of phosphorus (P) in the remaining mass of decomposing litter remained similar during the first four months in most of the species, which were having high C/N value. P remaining was also increases during the initial stage, which might be the contribution from the mycelial growth of fungus that multiplied during this time. P remaining in the litter mass decreases during the onset of monsoon in some species whereas it decreases at the last stage of decomposition for some species. The rapid disappearance of litter mass in *Colocasia esculenta*. *Ageratum conyzoides* and *Bauhinia variegata* caused by the intense decomposition activity resulted in decrease in P concentration during the first three months. The decrease was recorded up to 45% to 83% in these four species. The data in general show that the release of P from agroforestry species leaf litter occurred in the later stage of decomposition. As in the case of N the absolute content of P or the P remaining also showed a gradual decrease with increase in the time of decomposition. P immobilization was more in *Musa* and *Bambusa* species, immobilization occurred although the study period in *Erythrina indica.* P turnover rate was lowest in *Musa* sp (1.56) and P mineralization rate was highest in *Bambusa tulda*. On the basis of C/N ratio and decomposition rate constant different leaf litter can be organized from high quality to low quality residues. The sequence is *Ageratum conyzoides*>*Bauhinia variegata*> *Colocasia esculenta*> *Erythrina indica*> *Zingiber officinale*> *Artocarpus heterophyllus*> *Oryza sativa*> *Mangifera indica*> *Bambusa tulda*> *Musa* sp.> *Areca catechu*> *Livistona jenkinsiana.*

CONCLUSIONS

Traditional agroforestry systems in the humid tropical environmental conditions prevailing in the foothills of the Indian eastern Himalaya register seasonal and spatial variations in litterfall, accumulation and turnover. The canopy trees in the system dominate the litter production and their decomposition pattern influenced by micro-environmental variables help in nutrient cycling processes *in situ*. The intrinsic characteristics such as chemical quality of litter fractions too determine the decay pattern and decomposition rate of plant residues in traditional agroforests. Integrating this useful information into the process of decision-making on the species mixtures for a dynamic and resilient agroforestry system would help enhance production and productivity *per se*.

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