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Dynamics of Litter Carbon and Nitrogen in Forest Fallows following Shifting Cultivation in Mizoram, Northeast India

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Abstract

In this study, a field trial was carried out on organic matter, carbon (C) and nitrogen (N) dynamics of different litter components (i.e. leaf, branch, roots <2 mm and 2-5 mm) in forest fallows (3 years: FL-3, 5 years: FL-5 and 10 years: FL-10) at Muallungthu, Mizoram using litter bag techniques. The rate of organic matter loss and release of C and N was faster in leaf and fine root (<2 mm) compared to branch and coarse roots (2-5 mm). Further, litter mass loss rate was higher in longer fallow (FL-10) compared to shorter fallow (FL-3 and FL-5). Results showed that mass loss and release of C and N was largely depending on the initial litter quality, abiotic variables and litter microorganisms. Release of C followed the patter similar to that of mass loss, whereas, N release showed an initial release followed by a slow release or marginal increase that indicate the tendency of N immobilization. Results indicate that the addition of litter from the adjoining forest adds organic matter, C and N in shifting cultivation that may help in sustaining soil fertility and crop productivity of shifting agriculture sites in northeastern hill regions of Mizoram.

1. Introduction

Shifting cultivation, a primitive form of agriculture, has been carried out by about half a billion tribal populations in moist tropical forest areas of the World (ITTO, 2002). This is a prevalent form of agriculture in northeast India. During the practice, each year village community slashes a piece of forest land, wait it to dry and burn the biomass *in situ* followed by cropping for 1 or 2 years depending on the level of soil fertility. When the soil fertility decreases the nomadic population moved to other forest areas for cultivation and abandon the land as fallow for certain years (e.g. 20-30 years) to recover the ecosystem properties (Grogan *et al.,* 2012). This has led to modify the natural forest ecosystem into various land uses, for example, secondary forests, plantations and agroforestry systems. Land-use changes associated with agricultural abandonment may affect aboveground and belowground litter, particularly fine root turnover rates (Yang *et al.,* 2010) due to changes in abiotic environments. Litter decomposition and their influencing factors had been widely studied in various ecosystems worldwide (Silver and Miya, 2001). Studies have measured the above- and belowground litter production and decomposition in relation to vegetation succession following agricultural abandonment (Ostertag *et al.,* 2008) and forest disturbance (Yang *et al.,* 2010; Lalnunzira and Tripathi, 2018).

Mizoram is located in tropical hilly region of Northeast India where majority of the population depend on shifting agricultural practice for their livelihood for generations which is locally called *Jhum* where farmers sow seeds of desired crops manually without tilling the soil following slashing and burning of forest land (Tawnenga and Tripathi, 1997). In the past, this agricultural system was sufficiently productive, economically practical and ecologically efficient due to long fallow period (~20 years). However, in recent years as a result of considerable increase in population, the length of fallow periods has been significantly reduced to ~<5 years which has led to decline in soil fertility and crop productivity, and posed a serious threat to food security for the farmers (Grogan *et al.,* 2012). The common features of shifting cultivation practice of Mizoram is its steep slopes which causes land degradation and contaminating surface water quality in hilly region because of soil erosion. The main reasons for this may be improper land use and poor management systems which causes huge loss of fertile soil (~60 t ha^{-1}) every year through erosion that carries nutrients (Tripathi *et al.,* 2017).

Therefore, well organized land management would be required to sustain the crop production particularly in shifting cultivation dominated landscapes of Mizoram that can support the growing food demand for the population through scientific interventions which are ecologically sound, economically feasible and socially acceptable. During the course of slashing and burning of above ground biomass, almost equal or even more biomass resides in belowground roots undergo decomposition that releases organic matter and nutrients to the soil during the course of cultivation. Further, aboveground organic matter addition during shifting cultivation has been found to significantly increase crop productivity for 2 cropping cycle in a small scale field experiment (Wapongnunsang and Tripathi S.K., unpublished data). In the present study, we assessed decomposition kinetics of different components (leaf, branch and root litters) in succession forest slopes of Muallungthu village, Aizawl. The main objectives of the present study were: (1) to determine temporal variations in the rates of litter decomposition and nutrient release of various components (leaf, branch, fine and coarse roots) in shifting cultivation sites (2) and to find out the factors (abiotic and litter quality) affecting the rates of litter decomposition and nutrient release in different fallows following shifting agriculture in Mizoram.

2. Materials and Methods

2.1. Study site and the experiment

The experiment was conducted in Muallungthu village (23°38' N lat., 92°43' E long., 985 m altitude) 25 km away from Aizawl district of Mizoram. The study was conducted at three fallow lands of 3 years (FL-3) ($23^{0}36^{'}30''$ N lat. and $92^{0}42^{'}87''$ E long.), 5 years (FL-5) ($23^{0}35^{'}69''$ N lat. and $92^{0}43^{'}09''$ E long.) and 10 years old fallow (FL-10) ($23^{0}35^{'}66^{''}$ N lat. and $92^{0}48^{'}08^{''}$ E long.) in Muallungthu village, Mizoram. All sites are within 2 km distance. The temperature, humidity and rainfall data of the study site during the sampling period was presented in Figure 1. The ages of fallow lands were recorded by interviewing the land owner. The soil of the study sites belongs to order inceptisol and falls under red soil group. Soil is light to medium texture (sandy loam and clay loam) and slope of the land varied between ~35º and 40º (Hauchhum and Tripathi, 2017).

2.2. Soil collection and determination of physico-chemical characteristics

Soil samples (100-150 g) were collected from the upper (0-10 cm depth) from 12 random locations and composited as 4 replicated samples for each site. A total of 12 composited soil samples were collected from three (i.e. FL-3, FL-5 and FL-10) sites. The composited soil samples were enclosed in polyethylene bags and transported to the laboratory. The soil samples were divided into two parts, one part was used to determine soil moisture (SM), available phosphorus (P_{avail}), available nitrogen (NH_4-N, NO_3 -N) in field moist soil. The other part was air-dried for the analysis of total organic carbon (TOC), total Nitrogen (TN), Bulk Density (BD) and pH.

Soil pH was measured in a soil-water suspension (1:2.5 w/v H_2O) using a digital pH meter. Gravimetric soil moisture was determined as described by

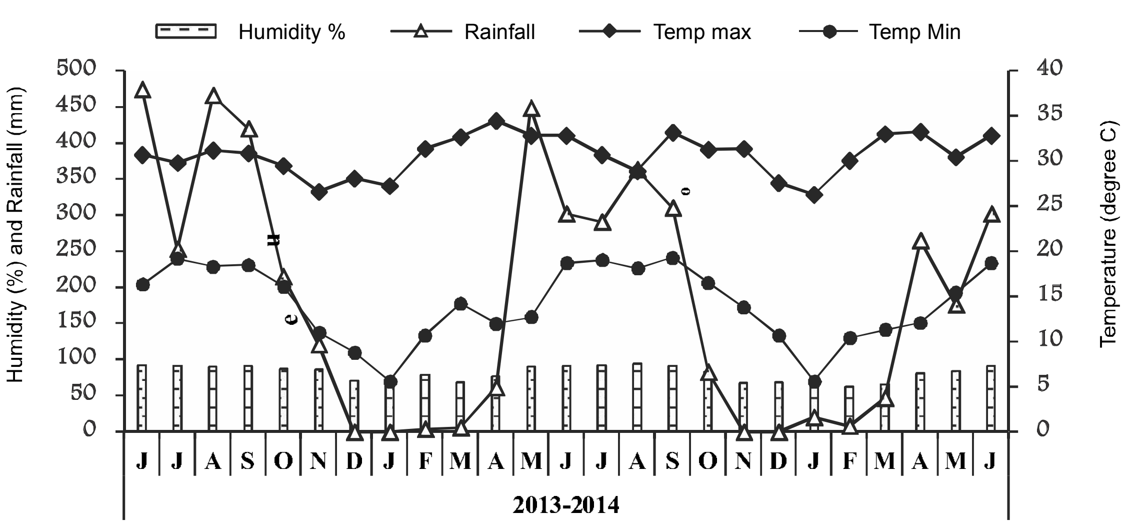

Fig. 1: Climate data of the study site showing total monthly rainfall (mm), mean monthly maximum and minimum temperature (°C) and mean monthly relative humidity for Aizawl district, Mizoram during 2013-2014. The climate data was collected from the weather forecast station of Pushpak, Zemabawk, Mizoram.

(Anderson and Ingram, 1993). TOC and TN were determined by a Heraeus CHN-O-S Rapid Auto-analyzer employing Sulphanilamide ($C_6H_8N_2O_2S$) standard. Bicarbonate (P_{avail}) was estimated using ammonium molybdo-blue color method (Allen *et al.,* 1974). NH_4-N was estimated by Indophenol Blue colour Method (Rowland, 1983). NO_3-N was estimated as method described by Jackson (1958). All values were reported on soil dry weight basis. BD (g cm^{-3}) was measured using a metallic tube of known inner volume to determine the dry weight of a unit volume of soil (Brady, 1984).

2.3. Determination of litter decomposition kinetics

At the time of slashing of vegetation during December-January 2012-2013, leaves and branch (<10 mm) were collected from different fallow lands (FL-3, FL-5, FL-10). At the same time, soils were dug out to recover roots and washed to remove adhering soil properties. Roots were further categorized as fine roots (<2 mm diameter) and coarse roots (2-5 mm diameter). Samples were air dried to constant weight. The litter bag technique was used to quantify decomposition rates (Bocock and Gilbert, 1957). A total of 360 nylon-net litter bags (10 cm x 10 cm, 2 mm mesh) containing 5 g of initial litter materials were prepared and randomly placed in all sites in July 2013. In addition, composite samples of all litter materials were stored for the analysis of initial litter quality. Above ground litter materials were placed on floor above the soil and root materials were buried inside the soil (0-10 cm) to determine the rate of decomposition. The mesh size (2 mm) was large enough to permit aerobic microbial activity and allow free entry of small soil animals. Five litter bags containing decomposing litter (per component) were randomly recovered at bi-monthly intervals from all sites. After recovery, the bags were placed in individual polythene bags and transported to the laboratory. The bags were then opened and recovered litter materials were brushed off to remove adhering soil particles and finally oven dried at 80°C for 48h to constant weight.

2.4. Analysis of litter chemical quality

Litter samples were ground and passed through 1mm mesh screen for chemical analysis. C and N concentrations were determined by a Heraeus CHN-O-S Rapid Auto-analyzer employing Sulphanilamide ($C_6H_8N_2O_2S$) standard. Initial lignin content of litter and roots was determined using Fibrotron Automatic Fibre Analyser System: Model: FRB 6, version 0.1 by employing 1NH_2SO_4 and Cetyl Trimethyl Ammonium Bromide (CTAB) as the detail procedure described in Lalnunzira and Tripathi (2017).

2.5. Calculation and statistical analysis

The mean relative decomposition rate (RDR) was calculated by using the formula:

$$\text{RDR (g g}^{-1}\text{ day}^{-1}) = ln\ (W_t\text{-}W_0) / (t_1\text{-}t_0) \qquad (1)$$

Where

W_0 = mass of litter present at time t_0, W_1 = mass of litter at time t_1, and t_1-t_0= sampling interval (days).

The daily instantaneous decay rate (k) of litter was calculated through the negative exponential decay model of Olson (1963):

$$W_t/W_0 = exp^{(-kt)} \qquad (2)$$

Where

W_0 = initial mass of the litter, and W_t = mass remaining after time t, the time series of C and N contents were used in this model to calculate the k (mineralization constant) values for C and N. As suggested by Olson (1963), the time required for 50% mass loss and C and N release was calculated as t_{50}= 0.693/k and for 95% mass loss as t_{95}= 3/k.

Correlation analysis was performed between abiotic variables (rainfall, temperature, humidity and soil moisture) and mass loss. One-way analysis of Variance (Tukey's HSD) was performed to determine variation in soil variables with fallow periods. All analyses were conducted using SPSS software package (16.0 Version).

3. Results and Discussion

3.1. Changes in soil physico-chemical characteristic across fallows

The soil (0-10 cm) were strongly acidic in nature (pH=4-5.5). This may be associated due to the addition of more cations during the course of burning event (Granged *et al.,* 2011). The soil BD decreased significantly from FL-3 (1.04 g cm^{-3}) to FL-10 (0.72 g cm^{-3}) as a result of higher accumulation of soil organic matters with fallow age (Sarkar *et al.,* 2015). Further, SM content and TOC also increased from 32 to 41% and 1.2 to 1.5%, respectively with increase in fallow ages. Further, soil nutrients like TN (0.10-0.14%), $P_{avail.}$ (10-17 µg g^{-1}) and available nitrogen (NO_3-N=3.2-5.9 µg g^{-1}); (NH_4-N =22-36 µg g^{-1}) all increased with fallow age (Kushwaha *et al*., 2000) (Table 1). Enhanced soil nutrients during the course of fallow recovery may be related to increased input of nutrients through addition of organic residues (Jiang *et al.,* 2009; Lungmuana *et al.,* 2017). The burning of huge biomass in higher fallow site may probably increases the possibility of losses of soil

Table 1: Annual range of soil characteristics at three different sites in Muallungthu village, Aizawl, Mizoram, n=4.

Fallow periods	pH	Bulk Density ($g\ cm^{-3}$)	TOC (%)	TN (%)	$P_{avail.}$ ($\mu g\ g^{-1}$)	NO_3-N ($\mu g\ g^{-1}$)	NH_4-N ($\mu g\ g^{-1}$)	C/N ratio
3 years	$4.30^{a}\pm 0.28$	$1.04^{a}\pm 0.12$	$1.27^{a}\pm 0.84$	$0.10^{a}\pm 0.09$	$10.30^{a}\pm 0.01$	$3.20^{a}\pm 0.07$	$22.45^{a}\pm 0.3$	12.7
5 years	$4.57^{ac}\pm 0.29$	$0.82^{ac}\pm 0.08$	$1.48^{b}\pm 0.41$	$0.12^{ac}\pm 0.05$	$14.15^{b}\pm 0.01$	$5.15^{b}\pm 0.06$	$30.97^{b}\pm 0.5$	12.3
10 years	$5.08^{bc}\pm 0.16$	$0.72^{bc}\pm 0.04$	$1.59^{c}\pm 0.62$	$0.14^{bc}\pm 0.05$	$17.34^{c}\pm 0.01$	$5.92^{c}\pm 0.04$	$36.66^{c}\pm 0.2$	11.3

Codes: *$p<0.05$; **$p<0.01$; TOC-Soil Organic Carbon; TN-Total Nitrogen; P_{avail}-Available phosphorus; NH_4-N-Ammonium Nitrogen; NO_3-N-Nitrate Nitrogen

organic matter and nutrients through erosion particularly on the steep slopes (Grogan *et al.,* 2012).

3.2. Changes in initial litter chemistry during fallow recovery

Initial litter chemical quality varied significantly among different litter components and fallow ages (Table 2). Lignin contents were significantly higher in branch (20-32%) and coarse roots (21-30%) and lower in leaf (13-29%) and fine roots (16-21%). Similarly, branch (30-41%) and coarse roots (35-44%) showed higher C content compared to leaf (33-35%) and fine root (29-31%). Further, N content in leaf (1.3-1.85%) and fine roots (0.9-1.3%) were significantly higher compared to branches and coarse roots (Table 2). Consequently, Lignin/N and C/N ratio was lowest in leaf and fine root compared to branch and coarse root. Noticeable changes in litter components were not recorded among different fallow length. Leaf and fine root components have been widely reported to have high N content compared to branch and coarse root (Tripathi and Singh, 1992a; Tripathi *et al.,* 2005, 2006).

3.3. Changes in mass loss and litter chemistry during decomposition

Percent litter mass remaining varied widely among the litter components and fallow length (Table 3). Maximum mass loss occurred in leaf followed by fine root, coarse root and branch in all sites. The percent mass remaining at the end of decomposition was: 5.8-12% in leaf, 22-29% in fine root, 25-33% in coarse roots and 29.4-37% in branch. The higher decomposition was recorded at FL-10 followed by FL-5 and FL-3 (Fig. 2). As reflected by RDR values, mass loss rate was faster in initial two months period in all litter components which varied between 25 and 32%, and the same decreases in the later stages of decomposition (Fig. 2). Similar findings have been reported in two species of *Tephrosia* (*T. candida* and *T. vogelii*) from Nairobi, Kenya (Munthali *et al.*, 2015) and in *T. candida* from Mizoram, India (Wapongnungsang *et al.*, 2017). The annual decay constant (k) for different litter component in the present study (3.3-6.9) were higher than those reported for dry tropical Sal forests (1.6-2.2) by Sharma *et al.* (1990) and bamboo savanna (1-1.5) by Tripathi and Singh (1992b). Most of the great literature has shown that variation in leaf decomposition rate among species categories depends greatly on litter quality (Tripathi *et al.*, 2006; Pandey *et al.*, 2007). Higher decay rate k in the present study suggests more decomposition of organic matter as a result of favorable climatic condition.

In the present study, lower C/N and lignin/N ratio

Table 2: Initial chemical composition (% except, C/N and lignin/N) of litter components (leave, branch, roots <2 mm, 2-5 mm) from three different sites (FL-3, FL-5 and FL-10 years) Muallungthu village, Aizawl district, Mizoram, n=5.

Sites	Components		Lignin %	C %	N %	Lignin/N	C/N
3 years	Leaves		13.6±11	33±1.2	1.31±0.12	10	25
	Branches		20.0±10	30±1.2	1.07±0.12	19	28
	Roots	<2 mm	15.7±11	29±1.1	1.11±0.15	14	26
		2-5 mm	21.0±12	35±1.0	0.99±0.11	21	35
5 years	Leaves		19.1±13	34±1.2	1.55±0.08	12	23
	Branches		27.1±11	37±1.1	1.29±0.12	21	27
	Roots	<2 mm	23.3±11	30±1.1	1.31±0.12	18	23
		2-5 mm	26.5±12	40±1.2	1.27±0.1	21	31
10 years	Leaves		29.3±12	35±1.2	1.87±0.12	16	18
	Branches		32.2±12	41±1.4	1.43±0.12	21	29
	Roots	<2 mm	21.2±12	31±1.0	1.51±0.15	14	21
		2-5 mm	30.2±12	44±1.1	1.36±0.11	22	32

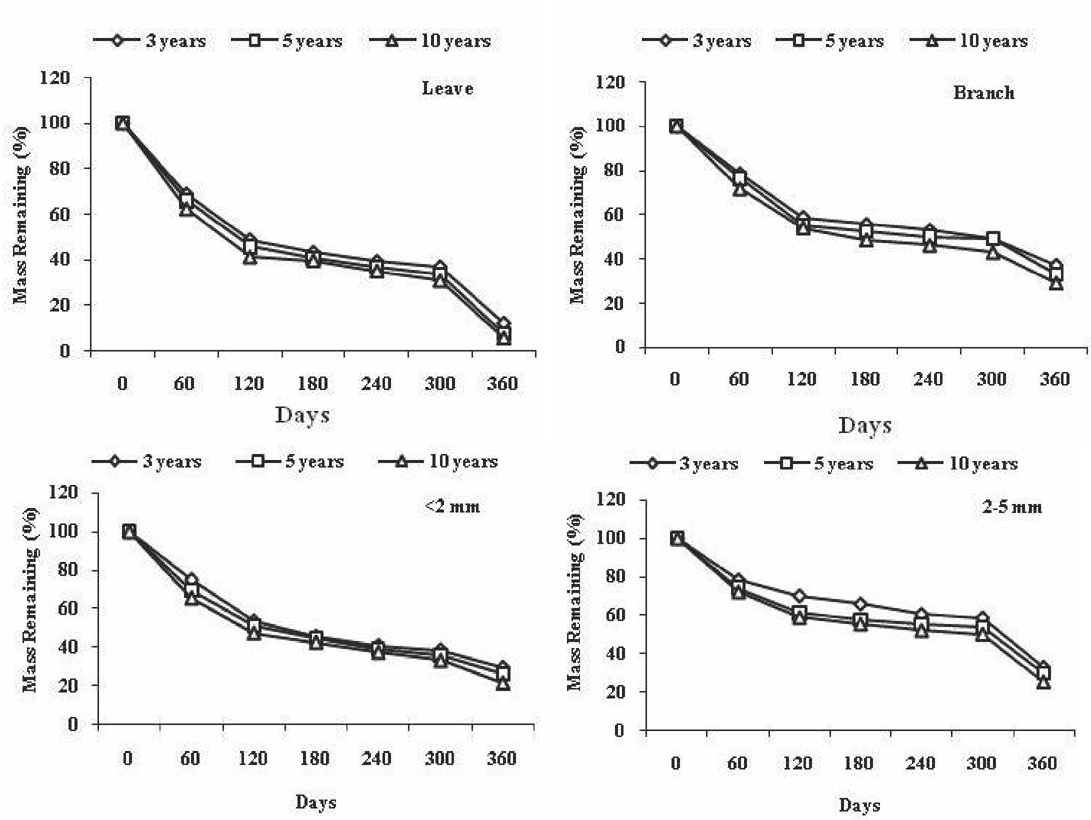

Fig. 2: Mass remaining after litter placement in days for four litter components in different sites (FL-3, FL-5 and FL-10 years), respectively.

in leaf and fine roots compared to branch and coarse roots (Table 2) reflected rapid decomposition in former than later. Rapid mass loss in fine roots could have been caused by chemical characteristics of the roots or by some attribute of the belowground decomposition environment (Ostertag and Hobbie, 1999). The ratios of lignin/N and C/N were found to play significant role during early and later stages of decomposition (Tripathi and Singh, 1992a; Tripathi *et al.,* 2006; Pandey *et al.*, 2007).

The initial mass loss in the first recovery may be related to the water soluble such as sugars, amino acids and soluble phenolics and labile substances during the initial period (Wang *et al.,* 2004). Further, slow rate of decomposition at later stage may be attributed to decline in easily decomposable compounds from the litter and increased amount of recalcitrant materials such as lignin, hemicelluloses and soil microbial products (Saviozzi *et al.,* 1997). Slow decomposition in branch and coarse root may be because of the presence of more stable polysaccharides like lignin, waxes and polyphenols (Zech *et al.,* 1997). The daily instantaneous decay constant (*k*), number of days required for 50% and 95% decomposition for various litter components were in the order: leaf>fine root>coarse root>branches (Table 3). Previous studies have shown that roots decompose more slowly particularly greater root (Vivanco and Austin, 2006) than other components among species. Our results suggest that root decomposition was influenced by root diameter i.e. faster in fine roots having high concentrations of hemi-cellulose and cell soluble (Ostertag and Hobbie, 1999).

3.4. Pattern of C and N release during fallow recovery

Generally, the pattern of C stock loss followed the pattern similar to that of mass loss in all sites (Fig. 2). However, the N stock loss showed a steady decrease followed by a slow release or slight increase in N stock which showed the tendency of N immobilization by microorganisms during the stage of decomposition followed by N mineralization (Barnes *et al.,* 1998) (Fig. 3). Fine roots and leaf litter showed a relatively greater release of N than other components. The effect of initial litter quality on the decomposition rate was evaluated by correlating annual mass loss of different components against litter quality parameters: C, N, lignin, C/N ratio and lignin/N ratio. The C/N ratio in branch and coarse

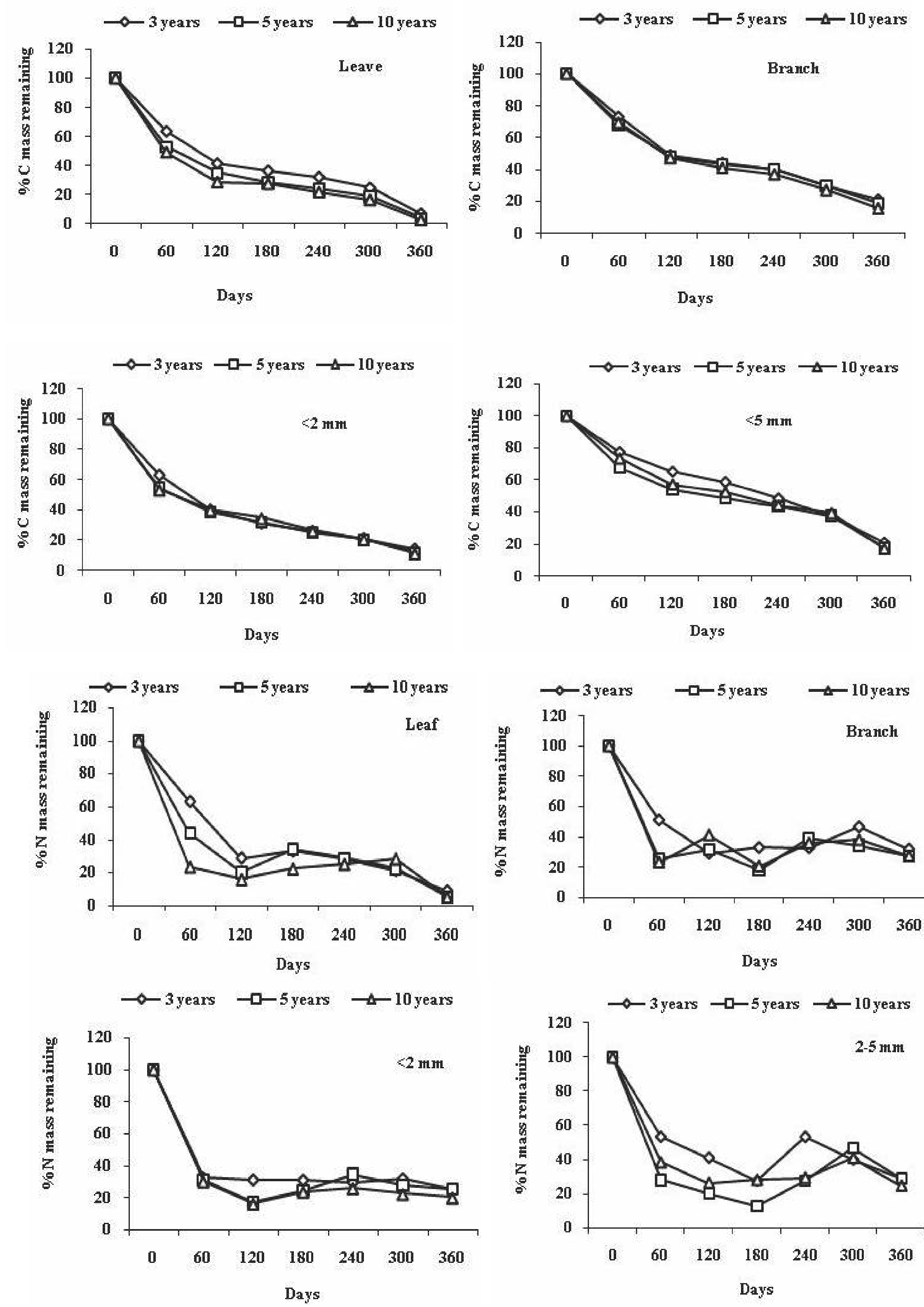

Fig. 3: Temporal changes in the amount of carbon and nitrogen stock in different litter components during the course of decomposition.

Table 3: Decomposition parameters and time required for various levels of decay (t_{50} 50%, t_{95} 95% mass loss), n=5.

Sites	Components	Mass remaining (% initial) 365 days	Annual decay rate (*k*)	t_{50} (days)	t_{95} (days)
FL-3	Leaf	12.0	5.81	119.30	516.45
	Branch	37.2	2.71	255.79	1107.33
	<2 mm	29.4	3.35	206.62	894.48
	2-5 mm	33.2	3.02	229.40	993.09
FL-5	Leaf	7.8	6.99	99.15	429.24
	Branch	33.2	3.02	229.40	993.09
	<2 mm	26.8	3.61	192.10	831.58
	2-5 mm	30.0	3.30	210.09	909.49
FL-10	Leaf	5.8	7.80	88.84	384.57
	Branch	29.4	3.35	206.62	894.48
	<2 mm	22.0	4.15	167.06	723.19
	2-5 mm	25.6	3.73	185.64	803.62

roots (Table 2) may partially be responsible for slow decomposition rate that affect the release of nutrients in soil (Fosu *et al.,* 2007). Hoorman (2010) reported that the critical values of C/N required for plant residues to transit from immobilization to mineralization was 20:1. The present result showed that the C/N ratio in litter component was above this critical value which tends to slow down the rate of decomposition in plant residues (Table 2).

3.5. Role of abiotic variables on mass loss, C and N release patterns

The values of correlation coefficient (r) of abiotic variables and mean mass loss rates in different components (corresponding to litter bag retrieval intervals) were: 0.42 for SM, 0.36 for rainfall, 0.51 for air temperature, 0.41 for soil temperature and 0.30 for relative humidity. All r values were significant at $p<0.01$. The highest litter decomposition rates in the wet season reflect the favorable effect of rainfall and associated variables on decomposition of different sizes of roots and litter in all sites. However, lower soil moisture and temperature during winter period reduced the activity of microorganisms in the soil which therefore reduced the rates of decomposition (Tripathi and Singh, 1992a; Wapongnungsang *et al*., 2017). In the present study, mass loss rate was significantly positively correlated with abiotic factors. This reflects that the rainfall and its associated variables like temperature and soil moisture significantly affected the litter decomposition in all sites by promoting litter microorganisms. The present study demonstrates that abiotic factors play vital role in litter decomposition and C and N release in tropical evergreen forest fallows of Mizoram, Northeast, India.

The study showed that the litter decomposition rate was faster in FL-10 compared to FL-3 and FL-5 (Mayer, 2008). This may be related to soil abiotic variables like soil moisture, soil temperature as these variables have been reported to play a vital role in decomposition especially in monsoon periods compared to winter period (Tripathi and Singh, 1992b; Ostertag *et al.,* 2008). The leaf and fine roots also decompose faster compared to branch and coarse roots. This related to litter chemistry (e.g. concentration of initial lignin) of these litter components. The leaf and fine roots decompose faster because of less lignin and C/N ratio in the initial litter compared to thick branches and coarse roots (Zech *et al.,* 1997).

4. Conclusion

Present study demonstrates that the litter residues have significant potential to enhance soil fertility and crop productivity in shifting fallow lands of tropical hilly region of Mizoram. Therefore, the impact of reduced fallow lands can be mitigated by the addition of locally derived litter from the adjoining forest to building up of soil organic matter and improving soil C and N cycling in shifting cultivation fallows. This may lead to sustain soil fertility that can enhance crop productivity and better livelihood options to '*Jhumias*' in the region.

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