Changes in Leaf Litter Decomposition as affected by Different Land-Use Practices in Nokrek Biosphere Reserve of Northeastern India

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Abstract: ***The study aims at the analysis of the litter decomposition pattern of the composite leaf litters collected from the different land use practices viz. shifting cultivation and coal mining prevailing in the buffer zone ecosystem of Nokrek Biosphere Reserve of Meghalaya. The results were compared with the data obtained from the core zone which is and undisturbed forest area. Highest annual decay rate (k) of mixed leaf litter decomposition under laboratory condition was observed in undisturbed core zone (1.76), followed in descending order by 10-12-yr. old jhum fallow to 1-yr. old fallow and then by the mine spoil (0.87). The reductions in the rate of leaf litter decomposition were 50 % in the jhum fallow and 51 % in the mine spoils compared to the core zone. Maximum nutrients (N, P and K) mineralization constants from the mixed leaf litter were observed in the core zone (0.71, 0.58 and 2.85 respectively) and minimum in the mine spoil (0.28, 0.21 and 1.46 respectively). In the jhum fallow there was 16 % loss of N release, 16 % loss of P release and 17 % loss of K release compared to the core zone. The corresponding values for the loss in the mine spoil were 26 %, 25 % and 18 %.***

Keywords: *Undisturbed forest, Jhum fallows, coal mine spoil, litter decomposition, mineralization*

1. Introduction

Decomposition of forest litter is the primary means for transferring nutrients into forms available for plant uptake, and is one of the most crucial processes in the biogeochemical cycle of the forest ecosystems [1]. Litter originating from both above- and below - ground parts, is the major pathway of supply of energy and N to soil in most terrestrial ecosystems [2]. During decomposition, some of the C and N are assimilated into microbial tissue and a part is microbially converted into resistant humic substances. The process of detrital decay is complex and is facilitated by the activities of wide range of macro- and micro- organisms[3]. These activities are influenced by numerous factors such as the chemical composition and physical structure of the detritus and environmental factors such as temperature, moisture, aeration and pH [4]. Much emphasis has been placed on the mass balance between leaf litter inputs and litter decomposition [5] and on the chemical composition of leaf litters affecting rates of decomposition [6]. Three essential factors control the decomposition of plant residues and the build-up of organic matter - namely resource quality and quantity, soil environmental conditions and the decomposer community [7].

Within an ecosystem, plant litter quality is the most important factor in determining the rate of decomposition [6, 8]. Therefore, the litter characteristics of the dominant plant species in an ecosystem strongly influence decomposition process [9]. Litter decomposition process starts both through leaching and through maintenance of an optimal residue moisture content for microbial catabolism [10]. Fungi, bacteria and invertebrates [11], soil temperature and soil moisture content [12] and the quality of litter in terms of its susceptibility to be attacked by decomposers influence decomposition rate. Decomposition has been related to initial concentration of nitrogen [13, 14], lignin [15] and carbon to lignin ratio [16]. Initial concentrations of C, N, lignin, polyphenols and their ratios with N are the major determinants in decomposition and N release [17]. Melillo *et al.* [18] observed a strong negative linear relationship between initial lignin / N ratio and disappearance rate of leaf litter. Swift *et al.* [19] concluded that leaching was the main factor influencing the initial weight loss of leaf litter.

Wardle *et al.* [13] and Quested *et al.* [14] found that litter mixture decompose faster than expected when the component species differ in their litter nutrient concentration, and found that interactions could be explained by a single litter chemistry parameter i.e., litter N concentration in both cases. However, Hoorens *et al.* [9] in their study found that litter decomposition rate was related to P concentration and not with the N concentration.

The present study analyzes decomposition of mixed leaf litters of the core zone, jhum fallows and mine spoils of Nokrek Biosphere Reserve of Meghalaya.

2. Methods

2.1 Sampling

Leaf litter decomposition and patterns of nutrient dynamics in decomposing litter were studied using nylon mesh (2 mm) litterbag (15 x 15 cm) [20]. For the decomposition study, newly senesced leaves were collected from the forest floor from 10-12 year old jhum fallow and the undisturbed core zone of the BR.

For the study of the litter decomposition under the laboratory condition, mixed leaf litters along with the samples of surface soil were collected from each of the selected sites. The soil was spread in a tray and the litterbags were kept on top of it and covered with the soil. The litterbags were taken out at 2, 4, 8, 16, 24, 32, 40 and 48th weeks following the method outlined by Okeke and Omaliko [21]. For the coalmine area, leaf litter samples were collected from the adjacent forested area and the decomposition pattern was studied by keeping the litter in the mine spoils in the similar fashion.

Analysis

The oven-dried leaf litter samples were powdered in a cyclotec (TECATOR) for the determination of the chemical composition. The ash content was determined by igniting the sample at 550°C for 6 hours in a muffle furnace. Carbon content was calculated as 50 % of the ash free weight. Nitrogen, phosphorus and potassium contents were determined according to Allen *et al.* [22] and Anderson and Ingram [23]. Lignin and cellulose were determined following the method outlined by Peach and Tracey [24].

Statistical analysis

Annual decomposition rate constant (k) was calculated from the data on the percent mass remaining using the negative exponential decay model [25]

$k = \ln (x/x_o)t$

Where, x_o=initial dry weight; x=weight remaining at the end of the investigation and t is the time in years. Similarly, N, P and K mineralization constants (k_N, k_P and k_K) were calculated by substituting dry weight with N, P and K contents in the foregoing formula [26]. The time required for 50 % (t_{50}) and 99 % (t_{99}) decay and mineralization were calculated as $t_{50} = 0.693/k$ and $t_{99} = 5/k$.

The data were analyzed using 2-way and 3-way analysis of variance (ANOVA) (fixed effect model) to test the effects of initial leaf litter chemistry, time and / or stand on the rate of decomposition and nutrient release. These were correlated with other properties of the soil/ spoil by computing linear regression models and coefficients of correlation (r) according to Zar [27].

3. Results

Decomposition of mixed leaf litter under laboratory conditions

Initial chemistry of the mixed litter

Carbon content in the leaf litters of different sites did not show significant variation. Nitrogen concentration was maximum (1.76 %) in 10-12-yr. old jhum fallow and minimum (1.22 %) in 1-yr. old fallow. Phosphorus concentration was relatively low ranging from 0.07 % in the litter samples collected near coalmine spoil to 0.10 % in 6-8-yr. old jhum fallow. Potassium concentration was also low, varying from 0.08 % in the jhum fallows to 0.04 % in the core zone. The C/ N ratio was maximum (37.30) in samples from 1-yr. old jhum fallow and minimum (26.67) in 10-12-yr. old jhum fallow (Table 1).

Wide variation in concentrations of cellulose (18-31 %) and lignin (20-42 %) were observed between the leaf litters of different sites. Litter of the 1-yr. old jhum fallow was poor in cellulose as well as lignin whereas those of the undisturbed core zone and 10-12-yr. old fallow were rich in both lignin and cellulose. Litter samples collected in near coalmine spoil was similar in chemical composition to that of 10-12-yr. old fallow, except in cellulose content which was low at this site (Table 1).

Table 1: Initial chemical composition (%, n=3±SE) of the mixed leaf litter samples collected from different sites in the BR

Sites	*C*	*N*	*P*	*K*	*Cellu-lose*	*Lignin*	*C / N*
Core zone*	47.50± 0.75	1.49± 0.003	0.08± 0.01	0.04± 0.002	29.00± 1.15	40.50± 4.50	31.88
Jhum fallows:							
10-12-yr. old *	47.00± 0.56	1.76± 0.001	0.09± 0.07	0.07± 0.001	31.00± 1.18	40.00± 5.00	26.67
6-8-yr. old *	46.50± 0.72	1.44± 0.001	0.10± 0.01	0.08± 0.002	19.00± 1.03	37.00± 4.50	32.29
1-yr. old *	45.50± 0.57	1.22± 0.009	0.09± 0.04	0.08± 0.002	19.00± 1.04	20.00± 2.50	37.30
Mean†	46.33	1.49	0.09	0.08	23.00	32.33	32.09
Mine spoil:							
Coal*	47.80± 0.35	1.70± 0.003	0.07± 0.08	0.05± 0.001	18.00± 1.12	42.00± 2.00	28.12

Weight Loss Pattern of the Mixed Litter

The weight loss of the leaf litters of different sites was similar, but the rate pattern varied significantly (*P*<0.01) between the different sites (Fig. 1).

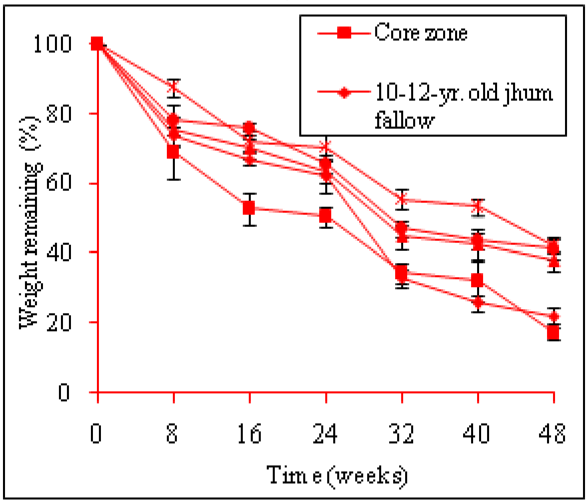

Figure 1: Mixed litter decomposition pattern under laboratory conditions. The values are means (±SE) of 2-3 replicate sites. The values are means (±SE) of 3-9 replicate sites.

At the end of the investigation (48th week), the average rate of weight loss was maximum (8.18 mg day^{-1}) in the undisturbed core zone and minimum (5.21 mg day^{-1}) in the coal mine spoil. The litter from core zone decomposed at a fast rate with 17 % of the original dry mass remaining at the end of the 48 weeks while that of coalmine spoil decomposed at a slow rate with 42 % of the original dry mass remaining during the same period. The annual decay constant (k) was lowest (0.87) in coalmine spoil and highest (1.76) in undisturbed core zone. The time required for 50 % decay (t_{50}) varied from 0.39 in undisturbed core zone to 0.80 in coal mine spoil. Similarly, t_{99} also increased from 2.84 to 5.75 (Table 2).

Nutrient mineralization

Nitrogen, phosphorus and potassium concentration in the mixed leaf litters of all the sites decreased during the decomposition. Nitrogen, phosphorus and potassium mineralization continued till the end of the investigation. However, it slowed down after 16 weeks in case of P and K (Fig. 2 a, b & c). Nitrogen mineralization constant varied from 0.28 in coal mine spoil to 0.71 in the core zone, for phosphorus it ranged from 0.21 in coal mine spoil to 0.58 in the core zone and for potassium, the constant value ranged from 1.46 in the coal mine spoil to 2.85 in the core zone. The values increased with the increase in the age of the jhum fallows for all the nutrients (Table 2).

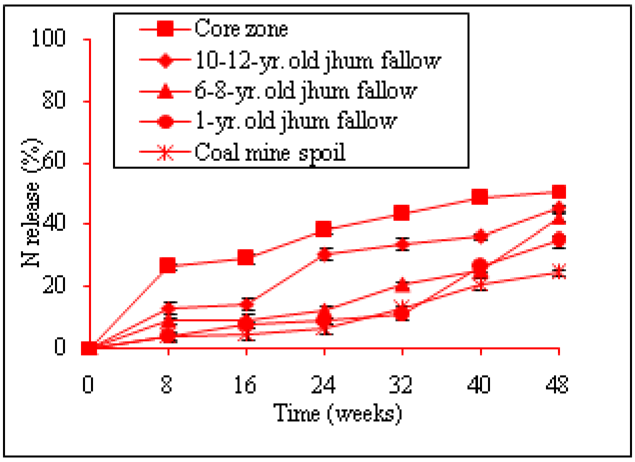

Figure 1 (a): Nitrogen (N) release pattern during decomposition of mixed leaf litter under laboratory conditions. The values are means (±SE) of 3-9 replicate sites.

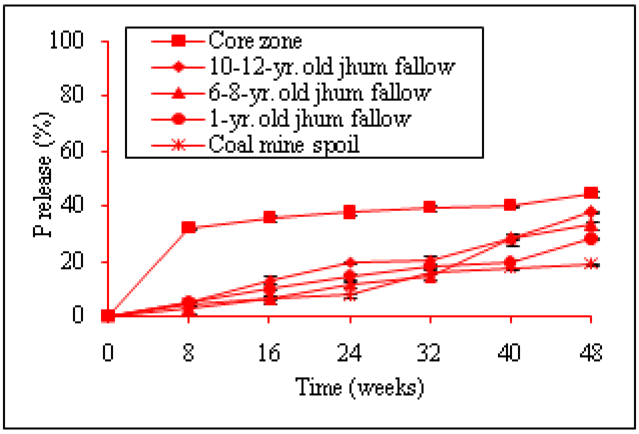

Figure 1 (b): Phosphorus (P) release pattern during decomposition of mixed leaf litter under laboratory conditions. The values are means (±SE) of 3-9 replicate sites.

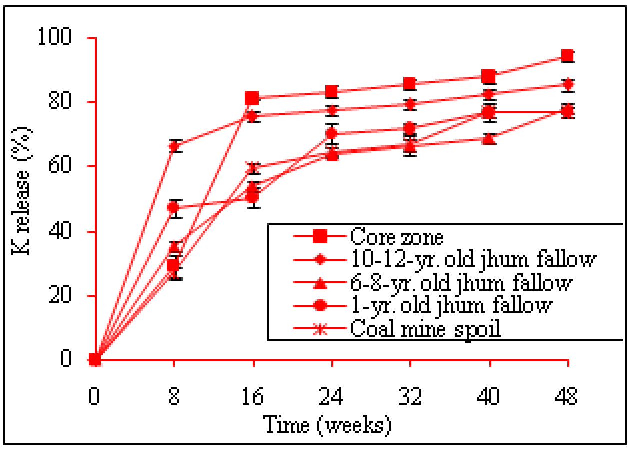

Figure 1 (c): Potassium (K) release pattern during decomposition of mixed leaf litter under laboratory conditions. The values are means (±SE) of 3-9 replicate sites.

Table 2: Annual decay constant (k) and mineralization constant (k_N, k_P and k_K) of the mixed leaf litters under laboratory conditions

		Core zone	10-12-yr. old jhum fallow	6-8-yr. old jhum fallow	1-yr. old jhum fallow	Coal mine spoil
Leaf decay	k	1.76	1.50	0.97	0.88	0.87
	t_{50}	0.39	0.46	0.71	0.79	0.80
	t_{99}	2.84	3.33	5.15	5.68	5.75
N Mineralization	k	0.71	0.60	0.55	0.43	0.28
	t_{50}	0.98	1.16	1.26	1.61	2.48
	t_{99}	7.04	8.33	9.09	11.63	17.86
P mineralization	k	0.58	0.47	0.40	0.33	0.21
	t_{50}	1.19	1.47	1.73	2.10	3.30
	t_{99}	8.62	10.64	12.50	15.15	23.81
K mineralization	k	2.85	1.91	1.52	1.47	1.46
	t_{50}	0.24	0.36	0.46	0.47	0.47
	t_{99}	1.75	2.62	3.29	3.40	3.42

4. Discussion

Decomposition of mixed leaf litter under laboratory conditions

In small-scale experiments of short duration, using defined cohorts of plant litters and more precise analytical methods, the effects of litter colonization by key fungal species during microbial succession become apparent [28]. Similarly under laboratory conditions, where much of the environmental variability encountered in the field can be factored out, forest floor materials from different sites and associated microbial communities, emerge as important variables in rates of litter decomposition [29, 30].

Since the chemical nature of the detrital materials differed at different sites as is evident from higher concentration of N in 10-12-year old fallow, as compared to the 6-8- and 1-year old fallow and higher concentration of cellulose and lignin in the core zone than the jhum fallows and mining site. This could be an important determinant of the observed variability in the decomposition rates.

Weight Loss Pattern and Rate of Mixed Leaf Litter Turnover

Fastest decomposition was observed in the undisturbed core zone where C/N ratio was 32 followed by the jhum fallows where C/N ratio was 27 and the mine spoils where C/N ratio was 28. In this case, litter with lower C/N ratio decomposed at a slower rate indicating the greater role of soil microflora in the decomposition process. Duchesne and Wetzel [31] also found that initial decomposition of *Populus tremuloides* and *Quercus rubra* litter was greatest in undisturbed plots and decomposition was fastest at the most fertile site. The litter turnover rate (k) varied between 0.87 and 1.76 and showed a progressive increase from the younger jhum fallow to the older fallow.

Decomposition rate (k) observed in the present study is higher than the rate 0.002-0.045 observed by Simmons and Hawkins [32] in the western streams, British Columbia. The k value of the undisturbed site is within the range (0.41 – 2.39) observed by Loranger *et al.* [33] in the semi-evergreen forests of Grande-Terre (Guadeloupe) but higher than the rate (0.60-0.97) recorded by Lin *et al*. [34] for four dominant tree species of the Fushan broadleaved forest of northeastern Taiwan.

Depending on the stage of the decomposition process, different chemical parameters of litter correlated well with mass loss. During the initial 8 weeks, mass loss was very fast which may be due to leaching of most soluble components after which it slowed down. At this stage, soil microfaunal activity becomes more important. Soil microfauna probably neglect leaves with higher phenol and lignin contents (Palm and Rowland 1997), and therefore their decomposition occurs at a slower rate. In contrast, leaves with high cellulose content, as in case of the mixed litter from the core zone and 10-12-yr. old jhum fallow, are preferred by soil invertebrates and therefore disappear more rapidly. Lignin and phenols are degradable only by a few organisms, in contrast to cellulose. Though the initial lignin concentration of mixed litter of the core zone was high, their decomposition was fast indicating the importance of the role of soil organisms in the soil system where the litters were kept.

Nutrient dynamics of mixed leaf litter

Gosz *et al.* [35] reported that N and P has long residence time on the forest floor as a result of relatively faster translocation, and greater immobilization by decomposers. Relatively long residence time (1.13 yr.) of N in the older regrowths indicated its greater immobilization in the forest-floor detrital mass compared to the young regrowth. Soil nutrients have larger and more frequent effects on litter nutrient dynamics than they have on decomposition [36]. The positive relationship obtained between nutrient release from decaying litter and soil TKN and P indicated a close relation between the two albeit indirectly (Table 3). According to Sanchez [37], the high quality litter released K at a higher rate and accumulated N at a higher rate.

Table 3: Correlation coefficients (r) between mass loss (mixed leaf litter) and nutrient release with substrate soil characteristics (n=16, $P<0.05$, ns=not significant)

Weight loss/ nutrient release	Soil parameters				
Variables	SMC	CEC	SOC	TKN	P
Total mass loss	0.53	0.97	0.60	0.76	0.80
N release	0.50	0.91	0.62	0.78	0.75
P release	0.51	0.97	0.63	0.81	0.81
K release	ns	0.99	0.62	0.82	0.84

Mineralization of nutrients was observed from the beginning till the end of the investigation (48^{th} week) though some workers [38] recorded immobilization of N in the first 12 months. Lin *et al.* [31] observed that over 3.5 years foliar N remaining mass still decreased with decreasing mass, mainly due to mineralization, in the four dominant tree species of the Fushan broadleaved forest of northeastern Taiwan. Regina [39] observed that there was a progressive loss of P in the decomposing oak leaves and a sharp loss of K but a tendency to retain N is seen in the semi-arid forests of Spain. Leaf litter decomposition in the island released more P after 1 week of decomposition [40].

Effect of shifting cultivation and mining on leaf litter decomposition and nutrient mineralization

Decay constant (k) of mixed leaf litter under laboratory condition showed 50 % reduction in both the jhum fallow and the mine spoil as compared to the core zone. The nitrogen mineralization was 39 % less in jhum fallow and 61 % less in the mine spoil. The reduction in phosphorus mineralization was 43 % in jhum fallow and 64 % in mine spoil. Reduction in potassium mineralization was about 48 % at both places. Thus, the adverse impact on litter decomposition and nutrient release from the decaying litter was more pronounced in mine spoils than jhum fallows in the buffer zone of BR.

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