LITTER DECOMPOSITION AND NUTRIENT MINERALIZATION DYNAMICS IN TWO BAMBOO SPECIES GROWING IN A 9-YEAR-OLD "JHUM" FALLOW

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ARUNACHALAM, A., UPADHYAYA, K., ARUNACHALAM, K. & PANDEY, H. N. 2005. Litter decomposition and nutrient mineralization dynamics in two bamboo species growing in a 9-year-old "jhum" fallow. Patterns of litter decay and nutrient mineralization rates of leaf and scale-leaf of *Bambusa balcooa* and *B. pallida* were determined using the litter-bag technique in a 9-year-old "jhum" fallow in the humid tropics of northeast India. C concentration was higher in leaf and scale-leaf litters of *B. pallida*, while N and lignin concentrations were greater in *B. balcooa* litter. Both leaf and scale-leaf litters of *B. balcooa* and *B. pallida* showed similar decomposition patterns. The daily decay constants did not differ significantly between the two litter types and bamboo species studied. Nonetheless, mass-loss rates during decomposition of the leaf and scale-leaf litters of both species showed positive correlations with incubation period (the time after burying the samples in the soil). In general, until 120 days of incubation, there was N immobilization and later during the study period rapid mineralization occurred. The release of N from *B. pallida* litter was greater than from *B. balcooa* as per k_N value. P was initially being immobilized followed by a gradual mineralization after 120 days of litter decomposition in *B. balcooa*. In *B. pallida*, no definite pattern was observed. The rate of weight loss and N release showed significant positive relationships with lignin and N concentrations and lignin/N, C/P and N/P ratios, and negative relationships with C and P concentrations and C/N ratio. However, mineralization rates of P did not show significant correlations with most chemical compositions of the litter except with initial P concentration, and lignin/N and C/P ratios.

Key words: Bamboo – decomposition – humid tropics – litter – nitrogen – phosphorus

ARUNACHALAM, A., UPADHYAYA, K., ARUNACHALAM, K. & PANDEY, H. N. 2005. Dinamik penguraian sarap dan pemineralan nutrien dalam dua spesies buluh yang tumbuh di bekas ladang "jhum" berusia sembilan tahun. Corak pereputan sarap dan kadar pemineralan nutrien bagi daun dan daun sisik *Bambusa balcooa* serta *B. pallida* ditentukan menggunakan teknik beg sarap di bekas ladang "jhum" yang beriklim tropika lembap di timur laut India. Kepekatan C lebih tinggi dalam sarap daun dan

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daun sisik *B. pallida* sementara N serta lignin lebih tinggi dalam sarap *B. balcooa*. Sarap daun dan daun sisik *B. balcooa* dan *B. pallida* menunjukkan corak penguraian yang serupa. Pemalar pereputan harian tidak berubah dengan signifikan antara dua jenis sarap dan spesies buluh itu. Walau bagaimanapun, kadar kehilangan jisim semasa penguraian sarap daun dan daun sisik kedua-dua spesies ini menunjukkan korelasi positif dengan tempoh pengeraman (tempoh selepas sampel ditanam dalam tanah). Pada umumnya, ketakmobilan N berlaku sehingga 120 hari pengeraman dan pada akhir kajian, pemineralan berlaku dengan cepat. Pembebasan N daripada sarap *B. pallida* lebih besar daripada *B. balcooa* mengikut nilai k_N. Pada awalnya P dalam *B. balcooa* tak mobil tetapi pemineralan berlaku beransur-ansur selepas 120 hari penguraian sarap. Tiada corak khusus diperhatikan dalam *B. pallida*. Kadar kehilangan berat dan pembebasan N menunjukkan hubungan positif yang signifikan dengan lignin dan kepekatan N serta dengan nisbah lignin/N, C/P dan N/P. Hubungan negatif pula dicerap dengan kepekatan C dan P serta nisbah C/N. Bagaimanapun, kadar pemineralan P tidak menunjukkan korelasi signifikan dengan kebanyakan komposisi kimia sarap kecuali kepekatan awal P, nisbah C/P dan lignin/N.

Introduction

Bamboo constitutes one of the dominant secondary successional vegetation types in the majority of the northeast Indian forests. Out of the 18 genera and 128 species of bamboo of India (Seethalaxmi & Gnanaharan 1998), Arunachal Pradesh alone harbours 16 genera and 63 species (Biswas 1988). Abandoned "jhum" (shifting agriculture) lands and forest clearings form favourable habitats for bamboos to invade, colonize and establish faster when compared with broadleaved native species (Haig *et al.* 1958), resulting in pure and/or mixed bamboo forests. Due to their abundance and faster regrowth, these bamboo species meet a variety of socio-economic and ethno-botanic human needs in the region. Nevertheless, the role of bamboos in soil nutrient cycling in degraded sites has been less studied (Maoyi *et al.* 1988, Tripathi & Singh 1992, 1994), unlike other broadleaved forest tree species (e.g. Singh & Gupta 1977, Laishram & Yadava 1988, Couteaux *et al.* 1995). Recycled nutrients from decomposing plant litter are among the main nutrient sources for maintaining growth of forest vegetation (Staaf & Berg 1981). Bamboos in this part of the world are mainly distributed in resource-poor soils. Hence the nutrient release from litter decomposition may play an important role in re-establishing the nutrient cycling in nutrient-poor soils, particularly when the ecosystem is undergoing recovery following disturbance (Arunachalam & Arunachalam 2002). The objective of the present study was to determine the rates of decomposition and nutrient mineralization through the leaf and scale-leaf litters of two lower altitude (100 to 600 m asl) bamboos, *Bambusa balcooa* Roxb. and *B. pallida* Munro., growing in a 9-year-old jhum fallow in the humid tropics of Arunachal Pradesh, northeastern India. The study was a part of a major research scheme that focused on the evaluation of bamboos in ecorestoration of degraded forestlands in this part of the country.

Materials and methods

Study site

The study was conducted in a bamboo forest (9 years old) developed on a fallow agricultural land (1.74 ha) located at an altitude of 132 m above sea level in the humid tropics of Arunachal Pradesh (26° 28'–29° 30' N, 91° 30'–97° 30' E), northeastern India. The average annual rainfall of the place is about 2500 mm with mean maximum and minimum air temperatures, 33 and 18 °C respectively. The climate is monsoonic with three seasons: spring/summer (March–May), monsoon (June–September) and winter (October–February). The soil is loamy sand and acidic (pH=5.9-6.5). Water holding capacity and clay content of soils under the canopy of *B. balcooa* are relatively greater (64 and 9.5% respectively) than under that of *B. pallida* (51 and 8%). On the other hand, soil organic C, total Kjeldahl N and available P are higher in *B. pallida* soil (1.5%, 0.05%, 10.69 $\mu g\ g^{-1}$) when compared with those of *B. balcooa* (1.0%, 0.04%, 8.89 $\mu g\ g^{-1}$) (Upadhyaya & Arunachalam 1999).

The selected bamboo species shared about 62% of the total plant density (110 plants ha^{-1}). Both species had grown to about 9 m over a 9-year fallow period. However, the number of culms per plant was significantly greater in *B. balcooa* (42) as compared with 27 in *B. pallida*. The average diameter of a culm was 6.99 cm in *B. pallida* and 6.23 cm in *B. balcooa*. The foliage litter of *B. balcooa* was 24% of the total leaf litter produced in the site (198.1 ± 11.92 g m^{-2}) while that of *B. pallida* contributed 26.5% of the total.

Sampling and analytical procedures

Freshly fallen foliage litter samples of the two bamboo species were collected during February 1999. The litter was sorted into leaves and scale-leaves and air-dried. Subsamples of litters were oven-dried at 105 °C for 24 h in order to determine their dry weights and for moisture correction. Ash content of litter was determined by igniting ground samples in a muffle furnace at 550 °C for 6 h. C content was calculated taking 50% of ash-free weight (Allen *et al.* 1974). Total Kjeldahl N was determined using semi-micro Kjeldahl procedure using phenolphthalein as indicator. Total P was estimated colorimetrically using the Olsen's molybdenum blue method (Anderson & Ingram 1993). Lignin and cellulose were determined using the acid detergent fibre method. The fibre content was measured gravimetrically (Anderson & Ingram 1993).

Air-dried litter samples equivalent to 10 g of oven-dry weight was placed in a nylon litter bag (1 mm mesh; 15 cm × 15 cm). Sixty bags were prepared for each litter fraction of a given species. The bags were equally distributed in five clusters in the site. In order to avoid disturbances from grazing animals, the bags were buried in the top 0–5 cm soil layer below the canopy of the respective species during March 1999. Five bags per litter type were retrieved at 60-day intervals. Each time, the sample from each bag was cleaned of adhering plant parts and soil particles, oven-dried at 105 °C for 24 h and weighed. The dried samples were ground and analysed for N and P using the standard procedures given in Anderson and Ingram (1993).

Computation and statistics

Organic matter decay, and N and P mineralization constants for the leaf and scale-leaf litters were computed using negative exponential decay model of Olson (1963): $X/X_0 = \exp(-kt)$, where X is the weight remaining at time t, X_0 is the initial weight, exp the base of natural logarithm, k the decay rate coefficient and t is the time. N and P mineralization constants (k_N and k_P) were calculated by substituting dry weight with N and P contents in the above formula (Singh & Shekar 1989). Further, the time required for 50% (t_{50}) and 99% (t_{99}) decay were calculated as $t_{50} = 0.693/k$ and $t_{99} = 5/k$.

The effect of initial litter chemistry and rainfall (data obtained from Doimukh Meteorological Station, which is within 1 km^2 radius of the study site) on the decay rate was tested using the linear regression function, $Y = a+bX$. Tukey's test was used to compare the means between litter types and species. LSD at $p < 0.05$ was also used to find out the time series differences in the litter mass and N and P concentrations. Polynomial equations were used to characterize the observed decay pattern (Zar 1974).

Table 1 Initial chemical composition of *Bambusa balcooa* and *B. pallida* litter

	B. balcooa		*B. pallida*	
	Leaf	Scale-leaf	Leaf	Scale-leaf
C (%)	44.56a	46.71b	47.82a	48.92b
N (%)	1.15a	0.34b	0.84a	0.34b
P (%)	0.031a	0.032a	0.023a	0.063b
Lignin (%)	31.2a	25.1b	29.3a	20.4b
Cellulose (%)	28.26a	29.63a	30.34a	31.05a
Fibre (%)	52.08a	35.41b	49.01a	34.31b
C/N	38.75a	137.38b	56.93a	143.88b
Lignin/N	26.96a	73.53b	34.52a	58.82b
N/P	37.10a	26.25b	14.78a	5.40b
C/P	1437.42a	1459.69a	2079.13b	776.51c
Lignin/P	1006.45a	784.38b	1273.91c	323.81d

Note: In each species, the values with similar alphabets across leaf and scale-leaf categories are not significant at $p < 0.05$ (Tukey's test). n=5

Results

Initial litter chemistry

C concentration and C/N ratio were higher in the two litter types of *B. pallida*, while N and lignin concentrations were greater in *B. balcooa* litters (Table 1). In general, the scale-leaves had greater C/N and lignin/N ratios (Table 1). N/P ratio was comparatively higher in leaf samples than in the scale-leaves in both species. Between species, *B. balcooa* registered greater N/P ratios.

Litter decay

Both leaf and scale-leaf litters of *B. balcooa* and *B. pallida* showed similar decomposition pattern. However, decomposition rate exhibited a significant variation in the two species of bamboo at least up to 180 days of incubation. In *B. balcooa*, during the initial 120 days of incubation, the rate of decomposition was slow both in leaf and scale-leaf litters. In *B. balcooa*, the decay rate sharply increased after 120 days of incubation and continued to increase until the end of the study period. However, in *B. pallida* the decomposition rate increased rapidly during the initial 60 days, which continued up to 120 days and then a slight decrease was noticed until 180 days, after which both species showed almost a similar pattern of decomposition. Nevertheless, the weight loss rate was almost similar in the two

Table 2 Daily decay/mineralization constants of leaf and scale-leaf of the two *Bambusa* species

Decay parameter	*B. balcooa*		*B. pallida*	
	Leaf	Scale-leaf	Leaf	Scale-leaf
Dry matter decay				
% mass loss day^{-1}	0.40	0.39	0.40	0.40
k (day^{-1})	0.022	0.016	0.022	0.022
t_{50} (days)	31.50	43.31	31.50	31.50
t_{99} (days)	227.27	312.50	227.27	227.27
N mineralization				
% release day^{-1}	0.41	0.32	0.38	0.30
k_N (day^{-1})	0.023	0.009	0.046	0.014
t_{50} (days)	30.13	77.00	15.07	49.50
t_{99} (days)	217.39	555.56	108.69	357.14
P mineralization				
% release day^{-1}	0.40	0.39	0.39	0.40
k_P (day^{-1})	0.021	0.016	0.019	0.027
t_{50} (days)	33.00	43.31	36.47	25.67
t_{99} (days)	238.09	312.50	263.16	185.19

Table 3 Dry mass remaining (g) and N and P concentrations (%) during *Bambusa* spp. litter decomposition

Day	*B. balcooa*						*B. pallida*					
	Leaf			Scale-leaf			Leaf			Scale-leaf		
	Dry mass	N	P	Dry mass	N	P	Dry mass	N	P	Dry mass	N	P
0	10.0	1.15	0.031	10.0	0.34	0.032	10.0	0.84	0.023	10.0	0.34	0.063
60	9.3	0.83	0.051	9.5	0.67	0.031	8.3	0.97	0.042	8.3	0.47	0.044
120	8.3	1.07	0.055	8.2	1.01	0.048	7.3	1.13	0.056	6.0	0.54	0.081
180	4.9	1.49	0.067	5.5	1.09	0.067	4.5	1.23	0.060	5.1	0.97	0.094
240	0.3	1.02	0.037	0.7	1.24	0.036	0.3	2.23	0.039	0.3	1.27	0.029
Mean	6.6	1.11	0.048	6.8	0.87	0.043	6.1	1.28	0.044	5.9	0.72	0.062
LSD at $p < 0.05$	0.7	0.05	0.003	0.8	0.07	0.003	0.8	0.11	0.003	0.7	0.08	0.005

Table 4 Dry matter and nutrient remaining (%) and N and P mineralization rates (% day^{-1}) in *Bambusa* spp. litter

Day/ incubation	*B. balcooa*						*B. pallida*					
	Leaf			Scale-leaf			Leaf			Scale-leaf		
	Dry mass	N	P	Dry mass	N	P	Dry mass	N	P	Dry mass	N	P
0– 60	93	67	167	95	200	100	83	100	150	83	133	67
61–120	83	75	167	82	267	133	73	100	200	60	100	83
121–180	49	58	100	55	167	133	45	75	150	51	167	83
181–240	3	3	3	7	33	100	3	13	5	3	13	2

Negative values represent nutrient immobilization.
Percentage values for weight remaining data have been integerized.

litter types of both species. The undecomposed litter at the end of the study remained highest in the scale-leaf of *B. balcooa* (7%) and in all other cases, only 3% of the initial mass was remaining at the end of the study (Table 3). The mean weight loss per day was similar in leaves and scale-leaves of *B. balcooa* and *B. pallida* (Table 2). The decay constants (k) did not differ much between the two litter types and bamboo species studied (Table 2). Nonetheless, mass-loss rates during decomposition of the leaf and scale-leaf litters of both the species showed positive correlations with incubation time ($r = 0.932–0.966$, $p < 0.001$).

Nutrient (N & P) dynamics

In the case of *B. balcooa* leaf, the concentration of N decreased during 0–60 days over the initial one and then increased consistently up to 180 days and again decreased. However, in the rest of the samples it increased with time (Table 3). Nevertheless, the N immobilization and mineralization rates were different through time. In general, until 120 days of incubation, there was a tendency of N immobilization and then a rapid mineralization occurred, which continued throughout the study period (Table 4). The release of N from bamboo litter was comparatively faster in *B. pallida* leaf and scale-leaf (k_N = 0.046 and 0.014) than in *B. balcooa* (k_N = 0.023 and 0.009) (Table 2).

In general, P concentration increased up to 180 days and decreased rapidly in both the species (Table 3). Initially P was immobilized followed by a gradual mineralization after 120 days of litter decomposition in *B. balcooa* and *B. pallida*. P mineralization patterns of leaf and scale-leaf litters were different. For instance,

Table 5 Correlation coefficients between initial litter quality and weight loss, and nutrient mineralization in leaf and scale-leaf of the two *Bambusa* spp. in northeast India (n=20)

Variable	Correlation coefficient (r)	p
Weight loss versus initial litter quality		
Lignin (%)	0.907	0.01
C (%)	- 0.707	0.01
N (%)	0.632	0.01
P (%)	- 0.980	0.01
Cellulose (%)	0.235	ns
Fibre (%)	0.542	0.01
Lignin/N	- 0.421	0.05
C/N	- 0.693	0.01
C/P	0.949	0.01
N/P	0.754	0.01
Lignin/P	0.930	0.01
N mineralization versus initial litter quality		
Lignin (%)	0.958	0.01
C (%)	- 0.720	0.01
N (%)	0.985	0.01
P (%)	- 0.709	0.01
Cellulose (%)	- 0.824	0.01
Fibre (%)	0.256	ns
Lignin/N	- 0.905	0.01
C/N	- 0.991	0.01
C/P	0.633	0.01
N/P	0.651	0.01
Lignin/P	- 0.108	ns
P mineralization versus initial litter quality		
Lignin (%)	- 0.103	ns
C (%)	- 0.107	ns
N (%)	0.328	ns
P (%)	0.580	0.01
Cellulose (%)	- 0.231	ns
Fibre (%)	- 0.368	ns
Lignin/N	- 0.449	0.05
C/N	- 0.190	ns
C/P	- 0.601	0.01
N/P	- 0.042	ns
Lignin/P	- 0.751	0.01

ns = not significant.

in *B. balcooa*, the k_P value was 0.021 for leaf litter, 0.016 for scale-leaf litter, while in *B. pallida*, the values were 0.019 and 0.027 respectively (Table 2).

Effect of litter quality on decomposition and nutrient release rates

Weight loss and nutrient release rates of different components were correlated with lignin, C, N and P concentrations and ratios of lignin/N and C/P and N/P. We found strong positive correlation of lignin and N concentrations with weight loss and N mineralization rates. However, only P concentration exhibited a significant positive correlation with P mineralization rate (Table 5). The other litter chemical quality variables like lignin/N, C/N, C/P and N/P exhibited either positive or negative correlation with weight loss and nutrient mineralization.

Discussion

Decomposition dynamics

Overall, the amount of litter remaining at the end of the study period was 3–7%. Nevertheless, the patterns of litter decomposition varied between litter types and species. In *B. balcooa*, the rate of decomposition was slow up to 120 days of incubation. This may be attributed to the time taken by micro-organisms to colonize and establish on the litter materials as these litter samples had greater lignin and cellulose contents when compared with *B. pallida.* (Alexander 1977, Arunachalam *et al.* 1996). During the monsoon, after 60–120 days of incubation, the decay rate rose due to greater microbial activity. In this context, several authors have reported faster rate of decomposition during the rainy season in the tropics (Swift *et al.* 1979). Maoyi *et al.* (1988) also opined that relatively higher temperatures and moisture conditions during the monsoon favoured decomposition of bamboo leaf litter in China. Coincidently, we obtained a significant relationship between mass loss and rainfall ($r = 0.451$, df=19, $p < 0.05$).

The C/N ratio of plant litter has frequently been negatively correlated with the decomposition rates (Floate 1970, Edmonds 1980). We also observed such a relationship in this study. Among other litter parameters, initial N and lignin concentrations influenced the litter decay pattern (Fog 1988, Tripathi & Singh 1992, Arunachalam *et al.* 1996). For instance, the faster rate of decay in leaf litter compared with scale-leaf litter is attributed to the greater initial N in the former (Table 1). Contrary to most of the reports (Meentemeyer 1978, Tripathi & Singh 1992, Arunachalam *et al.* 1996), we found a positive correlation between initial lignin concentration and rate of weight loss during decomposition. This suggests that apart from lignin, other parameters such as cellulose and polyphenols may have more influence on the decay rate of bamboo litters. For example, Tripathi and Singh (1992) found that roots having low cellulose contents decomposed at a faster rate. Nonetheless, we observed no relationship between cellulose content and litter decay rate in this study. Also, as opposed to the contention of Enriquez *et* *al.* (1993) that the greater the initial P concentration in the litter, the faster would be its decomposition, we observed a negative correlation between initial P and decay rate. This indicates that the decomposer population on bamboo litter was selective to nutrients like N and/or the P levels were low in the litter. Future work needs to test this hypothesis, for a better understanding of the role of P in the regulation of litter decomposition of bamboo residues. The rate of weight loss of bamboo litter in the present study was faster (as indicated by higher annual decay constants, 5.84 to 8.03) compared with the rates obtained by Tripathi and Singh (1992) for bamboo litter (0.43–2.76) in dry tropical bamboo savanna; and by Lugo and Murphy (1986) for tree leaf litter (1.28–2.04) in a subtropical forest.

N and P mineralization

The decreasing trend in N concentration from its initial level in the decomposing materials, except for *B. balcooa* leaf, may be attributed to leaching. And the increasing trend in N concentration after 120 days of progressive litter decay as observed in *B. balcooa* may be attributed to (i) microbial immobilization of N (Anderson 1973, Tripathi & Singh 1992, Arunachalam *et al.* 1996), (ii) throughfall input of atmospheric N (Bocock 1963, Paterson & Rolfe 1982) and (iii) atmospheric N_2-fixation (Wood 1974). Nevertheless, initial N concentration had a positive correlation with N release rates (Table 5). Tripathi and Singh (1992) reported that higher C/N ratios might cause a longer immobilization period. This was true for scale-leaf of the two bamboo species (Table 4) as they, with their greater C/N ratios, showed greater nutrient immobilization during the initial stages of litter decomposition as compared with the mineralization rates. Despite variations in N and P concentrations in the decomposing litter due to mineralization and/or immobilization, N and P stocks remaining in the litter were positively correlated to its dry mass ($r = 0.48–0.49$, $p < 0.05$). In this context, Cortrufo *et al.* (1999) reported no evidence for any increase in nutrient content in the litter, although the nutrient concentration increased owing to immobilization.

In the initial stages of decomposition (0–120 days), P mineralization in decomposing litter decreased or increased depending upon the initial P content of litter (Table 3). Shorter or longer P immobilization periods have also been reported by Gosz *et al.* (1973), Stohlgren (1988) and Prescott *et al.* (1993) for a variety of litter samples. As in this case, the classic pattern of nutrient immobilization followed by release was always more conspicuous for fast-decomposing litter than for litter decaying more slowly (Prescott *et al.*, 1993). This may also be explained by the role of "critical" P content in non-woody litters, above which P is released, as suggested by Rustad and Cronan (1988), Eason and Newman (1990) and Prescott *et al.* (1993). In the present study, the initial concentrations of P and C/P ratio in the litter samples were found to be good predictors of P release as evinced by the significant positive and negative correlations respectively (Table 5). However, other litter parameters, viz. C/N, lignin/N and N, did not show significant relationships with P mineralization. In this regard, our results with respect to P mineralization especially are contrary to the observations made by Tripathi and Singh (1992) for bamboo litter in a dry tropical savanna in northern India. Such differences could be due to variations in climatic and other parameters like microbial populations, type of microbial species involved in decomposition, and residue quality.

In general, nutrient immobilization was a prominent process during the decomposition of bamboo litter. It may be that the microbial population that colonized these litter fractions could not degrade the organic compounds stored in the litter as quickly because the foliage materials were sclerophyllous and lignin and fibre contents were also high. Myers *et al.* (1994) reported that organic residues having C/N ratio < 25 are of good quality and they release nutrients at a faster rate compared with low quality residues (C/N >25). Obviously, the litter fractions used in this study were all of low quality (C/N 39–57 for leaf litter; 137–144 for scale-leaf), which may have also influenced the nutrient dynamics during decomposition.

Conclusions

This study concludes the following: (i) the leaf and scale-leaf litters of both *B. balcooa* and *B. pallida* decompose at similar decay rates in the humid tropical fallow agricultural land, (ii) N and P mineralization rates differ between the scale-leaf and leaf litter, (iii) P release is faster, showing little difference in decay rate among litter types, whereas N release is rapid only in leaf litter samples, (iv) most of the litter parameters show significant relationships with weight loss and N mineralization patterns, whereas P mineralization is significantly correlated only with initial P content, and lignin/N and C/P ratios in litter materials, and finally (v) rainfall influences litter decay and nutrient release.

Given the overall comparable rates of decay and nutrient mineralization, the study suggests that both *B. balcooa* and *B. pallida* have tremendous potential in regulating soil nutrient pool through faster litter turnover, and therefore, can help in soil nutrient restoration *vis-à-vis* ecosystem reconstruction. It is also recommended that studies on the ecological role of bamboos in the restoration of degraded sites, particularly on hill slopes, of the humid tropics should address litter decomposition as a key unit for investigation, as this might give some useful information on the patterns and processes of soil nutrient dynamics that would help in understanding the species replacement during secondary succession, and/or to develop useful ecoscientific package for managing bamboo forests in general and "jhum" fallows in particular.

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References

ALEXANDER, M. 1977. *Introduction to Soil Microbiology.* 2nd edition. John Wiley, New York.

ALLEN, S. E., GRIMSHAW, H. M., PARKINSON, J. A. & QUARMBY, C. 1974. *Chemical Analysis of Ecological Materials.* Blackwell Scientific Publications, Oxford.

ANDERSON, J. M. 1973. The breakdown and decomposition of sweet chest-nut (*Castenea sativa* Mill) and beech (*Fagus sylvatica* L.) leaf litter in two deciduous woodland soils. II. Changes in carbon, hydrogen, nitrogen and polyphenol content. *Oecologia* 12: 275–288.

ANDERSON, J. M. & INGRAM, J. S. I. 1993. *Tropical Soil Biology and Fertility—A Handbook of Methods.* 2nd edition. CAB International, Wallingford.

ARUNACHALAM, A. & ARUNACHALAM, K. 2002. Evaluation of bamboos in eco-restoration of 'jhum' fallows in Arunachal Pradesh: ground vegetation, soil and microbial biomass. *Forest Ecology and Management* 159:231–239.

ARUNACHALAM, A., PANDEY, H. N., TRIPATHI, R. S. & MAITHANI, K. 1996. Fine root decomposition and nutrient mineralization patterns in a subtropical humid forest following tree cutting. *Forest Ecology and Management* 86: 141–150.

BISWAS, S. 1988. Studies on bamboo distribution in north-eastern region of India. *Indian Forester* 114: 524–531.

BOCOCK, K. L. 1963. Changes in the amount of nitrogen in decomposing leaf litter of sessile oak (*Quercus petraca*). *Journal of Ecology* 51: 555–566.

COTRUFO, M. F., RASCHI, A., LANINI, M. & INESON, P. 1999. Decomposition and nutrient dynamics of *Quercus pubescens* leaf litter in a naturally enriched CO_2 Mediterranean ecosystem. *Functional Ecology* 13: 343–351.

COUTEAUX, M. M., BOTTNER, P. & BERG, B. 1995. Litter decomposition, climate and litter quality. *Tree* 10: 63–66.

EASON, W. R. & NEWMAN, E. I. 1990. Rapid loss of phosphorous from dying ryegrass roots: the chemical components involved. *Oecologia* 84:359–361.

EDMONDS, R. L. 1980. Litter decomposition and nutrient release in Douglas-fir, red alder, western hemlock, and Pacific silver fir ecosystems in western Washington. *Canadian Journal of Forest Research* 10: 327–337.

ENRIQUEZ, S., DUARTE, C. M. & SAND-JENSEN, K. 1993. Patterns in decomposition rates among photosynthetic organisms: the importance of detritus C: N: P content. *Oecologia* 94: 457–471.

FLOATE, M. J. S. 1970. Decomposition of organic material from hill soils and pastures. II. Comparative studies on the mineralization of carbon, nitrogen and phosphorus from plant material and sheep faeces. *Soil Biology and Biochemistry* 2: 173–185.

FOG, K. 1988. The effect of added nitrogen on the rate of decomposition of organic matter. *Biological Review* 63: 433–462.

GOSZ, J. R., LIKENS, G. E. & BORMANN, F. H. 1973. Nutrient release from decomposing leaf and branch litter in Hubbard Brook Experimental Forest, New Hampshire. *Ecological Monograph* 43: 173–191.

HAIG, I. T., HUBERMANN, M. A. & DIN, U. A. 1958. *FAO Forest, Forest Production Study* 13 (Tropical Silviculture), Vol. 1.

LAISHRAM, I. D. & YADAVA, P. S. 1988. Lignin and nitrogen in the decomposition of leaf litter in a subtropical forest ecosystem at Shiroy hills in north-eastern India. *Plant and Soil* 106: 59–64.

LUGO, A. E. & MURPHY, P. M. 1986. Nutrient dynamics of a Puerto Rican subtropical dry forest. *Journal of Tropical Ecology* 2: 55–72.

MAOYI, F., MINGYU, F. & JINGZHONG, X. 1988. Leaf litter and its decomposition in bamboo timber stands. In *Proceedings of the International Bamboo Workshop.* Nov. 14–18, 1988.

MEENTEMEYER, V. 1978. Macro-climate and lignin control of decomposition rates. *Ecology* 59: 465–472.

MYERS, R. J. K., PALM, C. A., CUEVAS, E., GUNATILLEKE, I. U. N. & BROSSARD, M. 1994. The synchronisation of nutrient mineralization and plant nutrient demand. Pp. 81–116 in Woomer, P. L. & Swift, M. J. (Eds.) *The Biological Management of Tropical Soil Fertility.* TSBF-John Wiley and Sons.

OLSON, J. A. 1963. Energy storage and the balance of producers and decomposers in ecological system. *Ecology* 44: 322–331.

PATERSON, D. L. & ROLFE, G. L. 1982. Nutrient dynamics and decomposition of litter fall in floodplain and upland forest of Central Illinois. *Forest Science* 18: 667–681.

PRESCOTT, C., TAYLOR, B. R., PARSONS, W. F. J., DURALL, D. M. & PARKINSON, D. 1993. Nutrient release from decomposing litter in rocky mountain coniferous forests: influence of nutrient availability. *Canadian Journal of Forest Research* 23: 1576–1586.

RUSTAD, L. E. & CRONAN, C. S. 1988. Element loss and retention during litter decay in a red spruce stand in Maine. *Canadian Journal of Forest Research* 18: 947–953.

SEETHALAKSHMI, K. K. & GNANAHARAN, R. 1998. Two decades with the giant grass. *Evergreen* (KFRI Newsletter) 41: 1-5.

SINGH, J. S. & GUPTA, S. R. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. *Botanical Review* 43: 449–528.

SINGH, K. P. & SEKHAR, C. 1989. Weight loss in relation to environmental factors during the decomposition of maize and wheat roots in a seasonally dry tropical region. *Soil Biology and Biochemistry* 21: 73–80.

STAAF, H. & BERG, B. 1981. Plant litter input to soil. *Ecological Bulletin* 33: 147–162.

STOHLGREN, T. J. 1988. Litter dynamics in two Sierran mixed conifer forests. II. Nutrient release in decomposing leaf litter. *Canadian Journal of Forest Research* 18: 1136–1144.

SWIFT, M. J., HEAL, O. W. & ANDERSON, J. M. 1979. *Decomposition in Terrestrial Ecosystems.* Blackwell, Oxford.

TRIPATHI, S. K. & SINGH, K. P. 1992. Nutrient immobilization and release patterns during plant decomposition in a dry tropical bamboo savanna, India. *Biology and Fertility of Soils* 14: 191–199.

TRIPATHI, S. K. & SINGH, K. P. 1994. Productivity and nutrient cycling in recently harvested and mature bamboo savannas in the dry tropics. *Journal of Applied Ecology* 31: 109–124.

UPADHYAYA, K. & ARUNACHALAM, A. 1999. Contribution of microbial biomass to soil nutrient pool under the canopy of *Bambusa balcooa* Roxb. and *Bambusa pallida* Munro. In *Proceedings of the Regional Seminar on Forest Resources in North-East India—Problems and Prospects.* North East India Council for Social Science Research, Shillong, India.

WOOD, T. G. 1974. Field investigations under decomposition of leaves of *Eucalyptus delegatensis* in relation to environmental factors. *Pedobiologia* 14: 343–371.

ZAR, J. H. 1974. *Biostatistical Analysis.* 2nd edition. Prentice Hall, Englewood Cliffs, New Jersey.