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Litter decomposition and nutrient release in a bamboo plantation

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Abstract—Decomposition and nutrient release patterns of bamboo litter were studied in a bamboo plantation. Litter decay rates were assessed using the litterbag technique. The monthly decomposition rate (K) ranged from 0.03 (June, September, October) to 0.08 (November) for leaves, 0.02 (June) to 0.09 (November) for branches and 0.01 (May, June) to 0.06 (November) for culms. Rainfall, temperature and soil moisture content were significantly correlated with the decomposition rates of litter components. Resident times (years) of litter components, calculated by dividing the litter standing crop by annual litter fall, were ranked as follows: culms (0.85) > leaves (0.48) > branches (0.24). The turnover coefficients (per year) were: branches (4.11) > leaves (2.07) > culms (1.17). Nutrient element residence times in the litter standing crops were ranked: Ca (1.0) > P (0.92) > Mg (0.64) > N (0.36) > K (0.31). The results from this study indicate that litter decomposition and nutrient element losses in bamboo plantations are slower than typical lowland rainforests and more similar to tropical semi-deciduous forests.

Key words: Nutrient cycling; plantation bamboo; litter decomposition; nutrient release.

INTRODUCTION

Much of the energy originating from primary production is released during decomposition [1]. During this release, plant nutrients become available for recycling within the ecosystem. Thus, litter decomposition contributes to soil fertility through the regeneration of plant nutrients and the maintenance of soil organic matter. Decomposition and nutrient release processes are particularly important in tropical ecosystems, where soils are often naturally low in fertility and nutrient status [2].

Litter contains a considerable amount of the nutrients necessary for plant growth. In order to release these nutrients, litter must be fragmented and decomposed. Litter breakdown and mineralization is mediated by the decomposer community (soil and forest floor micro-organisms and fauna) [3, 4]. Decomposition rates are

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regulated by interactions within the decomposer community, the physiochemical environment and litter quality [5]. Litter quality refers to intrinsic chemical and structural characteristics that govern the activity of decomposer organisms, which partly determines the rate of organic matter decay [3]. Litter resource quality is determined largely by the species contributing to the litter standing crop. The influence of litter quality on decomposition and mineralization rates in tropical rainforest has seldom been investigated [3, 6–13], presumably because of the great heterogeneity of tropical forest ecosystems and the consequent difficulty in selecting species to investigate for a meaningful approximation of the decomposition rates for whole forests.

The objectives of this study were to determine decomposition and nutrient release patterns of leaves, branches and culms in bamboo plantations and, in addition, to relate decomposition and nutrient release of the various litter components to temperature, precipitation and soil moisture.

STUDY SITE AND METHODS

The study area located at Kallipatty, Tamil Nadu state, India, lies between 11°28′ and 12° latitude and 76°59′ and 77°47′ longitude. Its altitude is 540 m above sea level. The soil in the area is laterite, red to brown in colour and sandy loam in texture [14] with pH 7.4 to 7.8 and quantities of N, P, K, Ca and Mg of 360, 22, 180, 150 and 155 kg/ha, respectively. The mean temperature is 32°C and mean rainfall is 600 mm. The monthly temperature ranges between 15.5°C (Jan.) and 26.7°C (May), whereas the monthly rainfall ranges between 14.7 mm (Jan.) and 451 mm (Nov.).

Nursery management practices

A nursery area of 10 m × 5 m was prepared in the field and filled with a mixture of soil and sand (3:1). The seedlings were picked out from the polythene bags when about 7 cm in height. About 25–30 seedlings were planted in 1 m^2 of raised nursery bed. Watering was done 2–3 times a day and care was taken to avoid oversaturation. Nursery beds were provided with a thatch to protect the seedlings from direct sunlight.

Transplanting

The 9-months-old seedlings in the nursery were uprooted carefully and transplanted to the field. The seedlings were planted with 6 m × 6 m spacing in a 3 ha area with 250 seedlings/ha. The transplanted seedlings were watered two hours regularly in the morning and evening. Weeding was done as and when required. After 1 year the plantation was adequately irrigated at 15-day intervals. Care was taken to avoid water logging. The plantation was protected against damage by rodents, grazing and browsing animals.

Productivity of the bamboo stand

The productivity of the bamboo is assessed by the number of new culms produced annually. At a given site, the production of new culms mostly depends on the culms of the previous year, the degree of congestion and the clump age. The mean grand total per culm tripled in each of years 1 and 2. Increments then declined, although from the end of year 2 to the end of year 6 biomass rose from 17.5 kg to 70.1 kg.

Litter decomposition

A standard litterbag method was used to study decomposition rates. Bags were 20×20 cm and constructed from nylon with mesh sizes of 1.2 mm^2 for leaves and 2 mm^2 for branches. A randomised complete block design with five replicates was used. Freshly fallen leaf litter and branches from the bamboo plantations were collected from the plantation forest floor. Additionally, culms (diameter <2 cm) were collected from the plantation forest floor. Collections were taken to the laboratory, where they were air dried for at least 2 weeks to achieve relatively uniform moisture content. Materials were analysed for their initial nutrient contents. The initial nutrient concentration (%) of N, P, K, Ca and Mg were found to be 0.91, 0.08, 0.63, 0.45, 0.47 (leaves); 0.61, 0.06, 0.73, 0.33, 0.39 (culms); and 0.82, 0.07, 0.75, 0.34, 0.40 (branches), respectively. After drying, 20 g of mixed leaf and branch samples were put in the nylon bags in equal proportions and placed just above the mineral soil after carefully removing the surface litter. Culms were cut into 25-cm-long pieces, carefully labelled and placed in the field. The experiment was carried out for 1 year [15, 16]. A total of 180 (60 for each litter component) litterbags were installed on the plantation forest floor to study litter decay dynamics. Bags were retrieved at monthly intervals after placement. Five bags per litter component were collected during each sampling. Retrieved samples were sorted to remove insects and arthropods, dried (70°C), weighed and ground in a Wiley mill. The decay constant (K) was calculated following negative exponential decay model [17]:

$$K = \ln(X/X_0)/t,$$

where X_0 is the initial dry weight in gram, X is the dry weight remaining at the end of the sampling interval (gram) and t is the time interval in months.

The contents of the bags for each litter type were pooled for chemical analyses after oven drying and separate weighing. Sub-samples used for mineral analyses were dry-ashed and estimated for nitrogen and phosphorus [18], and for potassium, calcium and magnesium [19]. Rainfall was measured during the study period in a bulk rain gauge, read every 7–10 days and air temperature was recorded on a hygro-thermograph. Soil moisture was determined by oven-drying soil samples at 105°C for 24 h. Soil samples were taken each month from 0–20 cm depth. Composite samples of plantation forest floor mass were taken from three 0.2 m^2 quadrates at each of the five blocks every three months, and weighed after oven-drying at 70°C.

The samples were then ground in a Wiley mill, and analysed for N, P, K, Ca and Mg contents using the same laboratory procedures as for decomposing litter samples.

Litter turnover coefficient

Litter fall and standing crop collections were done [20]. Litter fall was determined at 15 circular traps (0.25 m^2) located at each of the five sites. The traps were made of plastic gauze bags (1 mm mesh) suspended from galvanized wire frames at a height of about 1 m. Litter was retrieved frequently to prevent significant decomposition or leaching of nutrients. Generally, collections were made every two weeks. Litter fall from individual traps at each site was combined to give bulked samples for litter components for each site and collection period. Litter fall was oven-dried at 65°C until constant weight was achieved. The litter turnover coefficient was determined [17] with the equation:

$$t_{1/2} = 0.693/K1,$$

where $t_{1/2}$ is the litter half life (in years) and $K1$ is the litter turnover coefficient, calculated as: litter standing crop (t_1) + litter fall ($t_{1,2}$) − litter standing crop (t_2)/mean litter standing crop (($t_1 + t_2$)/2) (all in kg/ha) [21].

In addition, monthly decay for litter standing stock was calculated as the reciprocal of the overall turnover coefficient for each month. Residence time was calculated by dividing litter standing crops and litter fall inputs.

Data on litter components were assessed using analysis of variance (ANOVA) tests and means were separated using Duncan's Multiple Range Test (DMRT) [22]. Pearson's correlation analysis was used to detect relationships between climatic factors (rainfall, temperature) and soil moisture on the decay rates of litter components.

RESULTS AND DISCUSSION

Changes in temperature and moisture availability are related to decomposition rates [23, 24]. The differences in temperature and moisture supply, and their interactions with the activity of decomposer organisms, can explain the large variations in litter decomposition rates existing between tropical and temperate forests [8–10, 25]. Furthermore, temperature, rainfall and soil moisture significantly affect the decomposition of litter, since they influence the level of the microbial population [26]. In this study, rainfall, temperature and soil water content were significantly correlated with the monthly decomposition rates of each litter component, and by the end of the experiment 82% of leaves, 68% of branches and 45% of culm were decomposed (Tables 1 and 2). The monthly decomposition rate (K) ranged from 0.03 (June, September, October) to 0.08 (November) for leaves, 0.02 (June) to 0.09 (November) for branches and 0.01 (May, June) to 0.06 (November) for culms.

Table 1.
Dry weight, loss of weight (g and %) and monthly decomposition rates of different litter components of bamboo plantations

	Remaining dry weight (g)			Loss of weight (%)			Decomposition rate ($-K$)		
	Leaves	Branches	Culms	Leaves	Branches	Culms	Leaves	Branches	Culms
Jan	20.00 ± 7	20.00 ± 6	20.00 ± 6				0.00 f	0.00	0.00 f
Feb	18.00 ± 7	18.81 ± 6	19.2 ± 6	10.0 ± 5	6.2 ± 4	4.1 ± 4	0.07 b	0.06 b	0.03 c
Mar	16.01 ± 6	17.30 ± 5	18.24 ± 6	11.1 ± 5	8.1 ± 5	5.2 ± 4	0.07 b	0.05 c	0.03 c
Apr	14.34 ± 6	16.09 ± 5	17.33 ± 5	10.4 ± 5	7.3 ± 5	5.1 ± 4	0.05 c	0.04 d	0.03 c
May	13.01 ± 5	15.24 ± 4	16.98 ± 5	9.3 ± 4	5.0 ± 4	2.0 ± 1	0.04 d	0.03 e	0.01 e
Jun	12.01 ± 5	14.68 ± 4	16.64 ± 4	7.7 ± 4	4.2 ± 3	2.3 ± 1	0.03 e	0.02 f	0.01 e
Jul	10.68 ± 5	13.80 ± 3	15.97 ± 4	11.1 ± 3	6.1 ± 4	4.4 ± 4	0.04 d	0.03 e	0.02 d
Aug	9.35 ± 4	12.56 ± 3	15.01 ± 4	12.5 ± 3	9.0 ± 6	6.1 ± 5	0.04 d	0.04 d	0.03 c
Sept	8.35 ± 4	11.77 ± 3	14.51 ± 3	10.7 ± 3	6.3 ± 4	3.3 ± 3	0.03 e	0.03 e	0.02 d
Oct	7.36 ± 3	10.83 ± 2	13.93 ± 3	12.0 ± 2	8.0 ± 5	4.0 ± 4	0.03 e	0.03 e	0.02 d
Nov	5.02 ± 2	8.05 ± 2	12.26 ± 2	31.8 ± 8	25.7 ± 8	12.3 ± 8	0.08 a	0.09 a	0.06 a
Dec	3.68 ± 1	6.43 ± 1	11.03 ± 1	26.6 ± 7	20.1 ± 7	10.1 ± 7	0.04 d	0.05 c	0.04 b

Different lower case letters between rows indicate statistical significance ($P < 0.05$).

Table 2.
Pearson's correlation coefficient (r) values for decomposition rates in litter components (leaves, branches and culm), with rainfall, temperature and soil moisture in bamboo plantations ($P < 0.005$)

	Rainfall		Temperature		Soil moisture	
	r	P	r	P	r	P
Leaves	0.740	0.006	0.975	0.000	0.973	0.000
Branches	0.679	0.015	0.834	0.001	0.893	0.000
Culm	0.593	0.042	0.685	0.014	0.744	0.006

In order to compare these results with other studies, published annual decay rates were divided by 12 to yield an average monthly rate. The results presented here were most consistent with those from temperate or drier climates. Melillo *et al.* [27] reported an annual decay rate coefficient of 0.47 to 0.88 for temperate hardwood species. Annual decay rate coefficients for a Sierra Nevada forest in California varied from 0.78 to 0.80 [28]. For moist deciduous forests of the Western Ghats in Peninsular India, annual decay rate coefficients ranged from 0.29 to 0.44 [29]; and ranged from 0.2 to 0.26 for a Mediterranean forest in Italy [30]. In contrast to published reports from the tropics, the decay rate coefficients observed in bamboo plantations were rather low compared with other tropical forests [8–13, 31].

Litter standing crop was variable, and averaged 3.05 t/ha for leaves, 1.64 t/ha for culm and 0.45 t/ha for branches. The values are closer to the range found for lowland forests in the neotropics by Anderson *et al.* [6] and for semi-deciduous forests in South-East Brazil [32] for forest floor leaf litter. Residence time of litter standing crop is mostly based on soil characteristics, vegetation structure, species composition and phenology [32, 33]. In the bamboo plantation forest, residence times (year) of litter standing crops were: culm (0.85) > leaves (0.48) > branches (0.24). The turnover coefficients (per year) for branches, leaves and culm were 4.11, 2.07, and 1.17, respectively.

The nutrient element residence times in the litter standing crops were: Ca (1:0) > P (0.92) > Mg (0.64) > N (36) > K (0.31) (Table 3). Chemical composition is an intrinsic property of the litter which determines the turn-over rate of organically-bound nutrients [29]. It is known that the decomposition of litter includes the three stages of leaching, accumulation and release [33]. In the present study, Ca, P and Mg had a long retention time, while N and K were released rapidly.

In summary, the magnitude of nutrient release into the soil system through litter decay is dependent on climate, floristic composition and soil fauna. Implicitly, forest ecosystems influence nutrient release patterns in a substantial manner. Furthermore, each bamboo plantation forest has its own litter fall pattern, which differs in composition, chemical and biochemical characteristics, and nutrient release rates. Information pertaining to the initial macro element composition and litter decay rate would provide a mechanism for better understanding nutrient release patterns into the various ecosystems. Lower quality litter is characterized by slower turnover,

Table 3.
Mean ± SD of litter element inputs, element contents (both in kg/ha per year) and the element residence time (years) in fine litter standing crops (kg/ha) in bamboo plantations

		N	P	K	Ca	Mg
Leaves	Litter fall inputs (L)	39.81 ± 5.01	6.31 ± 1.05	20.84 ± 2.21	113.6 ± 15.90	25.26 ± 3.51
	Litter standing crops (X)	13.12 ± 3.03	4.98 ± 0.83	6.84 ± 1.05	78.98 ± 4.81	14.3 ± 3.06
	Residence times (X/L)	0.33 ± 0.01	0.79 ± 0.05	0.33 ± 0.01	0.69 ± 0.15	0.57 ± 0.04
Culm (<2 cm)	L	7.30 ± 1.51	1.21 ± 0.09	3.3 ± 0.23	28.2 ± 3.98	4.07 ± 0.81
	X	5.31 ± 0.52	2.82 ± 0.21	1.82 ± 0.04	64.65 ± 5.20	5.68 ± 1.51
	X/L	0.73 ± 0.12	2.33 ± 0.20	0.55 ± 0.03	2.29 ± 0.91	1.48 ± 0.09
Branches	L	12.64 ± 3.01	2.31 ± 0.30	6.14 ± 1.02	8.38 ± 2.42	3.98 ± 1.02
	X	2.91 ± 0.15	1.25 ± 0.02	0.9 ± 0.07	6.78 ± 2.01	1.37 ± 0.09
	X/L	0.23 ± 0.01	0.54 ± 0.03	0.15 ± 0.01	0.81 ± 0.06	0.33 ± 0.001
Total	L	59.71 ± 5.10	9.83 ± 1.11	30.26 ± 4.30	150.1 ± 15.09	33.1 ± 4.65
	X	21.30 ± 3.51	9.05 ± 2.50	9.58 ± 2.10	150.2 ± 14.30	21.2 ± 3.81
	X/L	0.36 ± 0.01	0.92 ± 0.10	0.31 ± 0.001	1.00 ± 0.01	0.64 ± 0.05

as illustrated by the differences in decomposition rates and residence times of the branches, leaves, and culm litter components in this study. Other studies have also noted that low initial nutrient concentrations resulted in higher litter accumulation rates [25, 27, 34]. The results from the bamboo plantations forests are consistent with these observations. The litter decomposition decay rates in bamboo plantations forests are relatively lower than other tropical lowland rainforests, and are more similar to those of tropical semi-deciduous forests. Lower decomposition rates are associated with the accumulation of forest floor litter, reflected by the higher litter standing crop in the bamboo plantation forests compared to other tropical lowland rainforests.

CONCLUSIONS

The results of the study in bamboo plantations emphasize the importance of the application of external fertilizers after the harvest.

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