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Litter fall, decomposition and nutrient release dynamics of *Thyrsostachys oliveri* gamble in humid tropics of Kerala, Southern India

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Abstract

Thyrsostachys oliveri is a bamboo species native to Myanmar cultivated in Arunachal Pradesh, Uttar Pradesh, Kerala and Tamil Nadu, India. Due to multifarious uses, this species has been preferred by farmers for large-scale cultivation all over India. Little is known about litter production, decomposition and nutrient release dynamics of this species. Litter dynamic studies are imperative, prior to integration of a species into any plantation program or agroforestry systems. The present study is framed to investigate the litter production, decomposition and nutrient release dynamics of T. oliveri. Litter production during 2010-2011 was quantified using specially designed litter traps made of bamboo baskets with a diameter of 1 m and depth 10 cm. Litter decomposition was studied using nylon litter bag techniques. The total annual litter production of this species was to the tune of 4.488 t ha^{-1}. The major share of total litterfall in T. oliveri was contributed by leaves (93.60±0.99 %) followed by branches (5.82±0.99 %) and culm sheaths (0.76±0.75 %). Litter production followed a biphasic pattern with a major peak in February 2011 and minor peak in July 2010. Weight loss expressed as percentage of the original dry weight decreased exponentially with time and the mass loss in T. oliveri was a good fit to exponential decay model. The decomposition rate constant of T. oliveri was 0.009 day^{-1} and the half-life was 77 days. The release of nutrients from the decomposing litter was in the order Mg > N > Ca > P > K.

Keywords: *Thyrsostachys oliveri*, litterfall, litter decomposition, nutrient release, decomposition rate

Introduction

Bamboos are fast-growing, arborescent grasses belonging to the family Poaceae, subfamily Bambusoideae, tribe Bambuseae. It is multipurpose species with more than one thousand five hundred recorded uses. The Government of India has launched two bamboo missions viz., National Mission on Bamboo Applications (NMBA) and the National Bamboo Mission (NBM) under Ministry of Science and Technology and Ministry of Agriculture and Co-operation, respectively, to focus on bamboo sector development. *Thyrsostachys oliveri* Gamble is a moderate sized tropical clumping bamboo with rather small leaves and persistent culm sheaths. Usually, the culms are 15–25 m high, 5 cm in diameter, bright green with the whitish silky surface when young, greyish green to light white in colour of maturity, thick-walled (2–2.5 cm), internodes 40–60 cm long. It was introduced to India from the native Myanmar and is being cultivated in Arunachal Pradesh, Uttar Pradesh, Kerala and Tamil Nadu. Culms of *T. oliveri* are in great demand for construction purposes, reinforcement for concrete slabs, poles, basketry and handicrafts. Young shoot is edible. The culms are also in good demand for pluckers and banana props. Because of its small clump size, straight growth and branching only from top one-third of the culms, it is the most preferred species by farmers for growing in homesteads. It is identified as one of the priority species for large-scale cultivation in India by NMBA (Haridasan and Tewari, 2008).

Plant litter acts as the temporary sink for nutrients and slow release of nutrients guarantees the permanent contribution to the soil. Litter decomposition plays a major role in maintaining soil fertility in terms of nutrient cycling and formation of the soil organic matter (Singh *et al*., 2007; Guendehou *et al*., 2014; Bargali *et al*., 2015). Litter dynamics studies are crucial in the nutrition budgeting in tropical ecosystems where vegetation depends on the recycling of the nutrients held in the plant debris (Prichett and Fisher, 1987). Data on its litter production and decomposition dynamics is vital, prior to the introduction of bamboos into farmer's field. Decomposition of litter by which organic matter and nutrients are returned to the soil is a primary mechanism and has received substantial attention in sustainable soil fertility. However, the litter dynamics studies of bamboos are scanty and most of the available literature is limited to monopodial bamboo species. No data is available on the litter dynamics of *T. oliveri*. With this background, the present study was formulated to understand the litter production, decomposition and nutrient release dynamics of *T. oliveri*.

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Table 1: Details of management practices adopted for *Thyrsostachys oliveri*

Sr. No.	Management practice	Particulars
1	Spacing	5 x 5 m
2	Pit size	60 x 60 x 60 cm
3	Fertilizer	10 kg FYM + 1 kg neem cake per plant at the time of planting. Afterwards FYM was applied @ 10 kg per plant every year
4	Irrigation	Once in a week during summer months in first two years. Thereafter no irrigation was done.
5	Weeding	Two weeding's in the first year and one each in second and third year

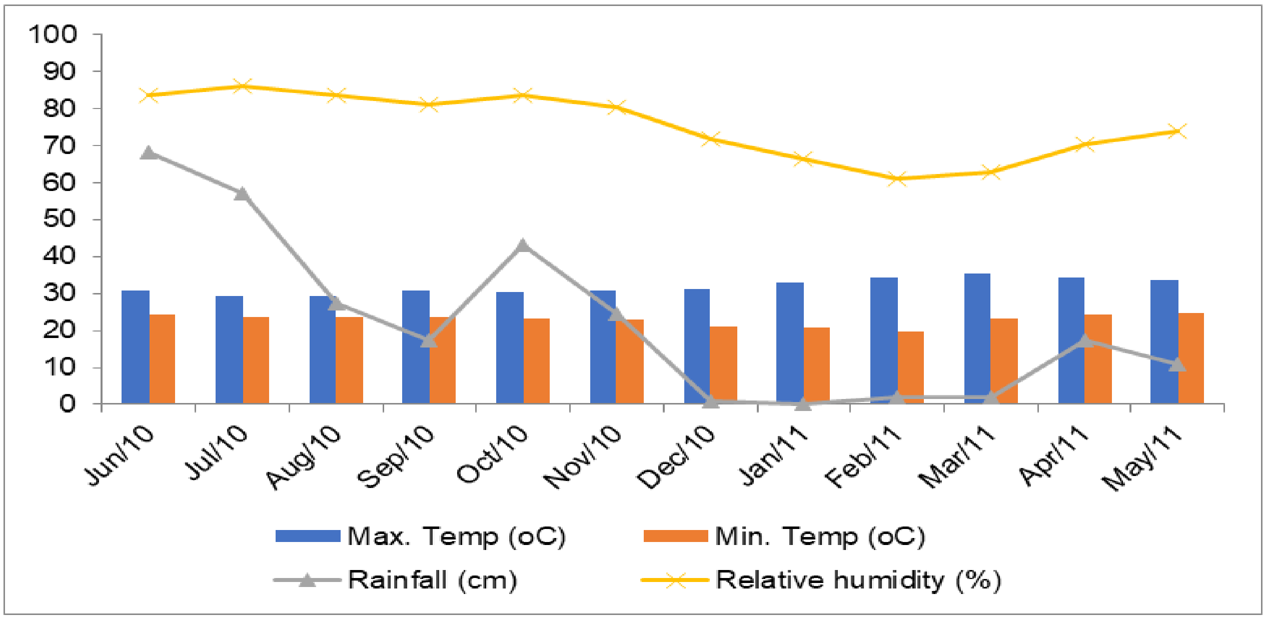

Figure 1: Change in monthly rainfall, relative humidity and maximum and minimum temperatures during study

Materials and Methods

Study area

The present study was conducted during July, 2010 to May, 2011 in a six-year-old *T. oliveri* plantation at Alanellur (N 11O 0' 38.2" and E 76O 20' 46.48''), Palakkad district of Central Kerala, India. The average weather parameters of the area are given in Figure 1. The plantation was established in a progressive farmers' field as block planting in 2005 with an espacement of 5m x 5 m. In the field, there were 60 bamboo clumps within 0.15 ha area and we selected three sample plots in the field. Each plot has sixteen bamboo clumps and the eight boarder clumps were kept as border plants to avoid the edge effect. The details of management practices adopted during the establishment of the plantation are given in Table 1.

Methods

Litterfall of *T. oliveri* was quantified using the specially designed litter traps made of bamboo baskets with a diameter of 1 m and depth 10 cm placed in the centre of sample plots. The litter in the traps was collected at monthly intervals and oven-dried at 70 °C to constant weights. Litterfall was computed on a unit area basis for each month and monthly litterfall data were summed to obtain the annual litter production. Decomposition rates were calculated by adopting standard litterbag techniques (Jijeesh and Seethalakshmi, 2016a) using nylon litter bags. Freshly abscised bamboo litter was collected during the peak litterfall period (February, March 2010) from the floor under the bamboo plantation. Proximate composition of litter was determined in sub-samples (500 g x 5). Weighed samples (30 g) of air-dried litter were placed in 28 x 23 cm nylon litter bags (2 mm mesh size) and 80 such bags were prepared. Litter bags were placed under the closed canopy of *T. oliveri* on the first week of June, 2010. Five samples were retrieved at monthly intervals until 95% decomposition of the litter was observed. The residual material from the monthly retrieved litter bags was separated carefully from the adhering soil particles using a small brush. Litter samples from each bag were oven dried at 70ºC to constant weight. Mass loss over time was computed using the negative exponential decay model (Olson, 1963). The time required for 50% (t50) and 99% (t99) decay was calculated as t50 = 0.693/k and t99 = 5/k.

Initial litter chemistry was determined prior to incubation of the litter sample. Total carbon content of the initial sample was estimated using Euro vector (EA 3000) CHNS Elementar analyzer and other nutrients through standard procedures. To determine the nutrients in litter retrieved at each sampling period, litter samples were ground in a Wiley mill for analysis. Nitrogen and phosphorus were estimated using Continuous Flow Analyzer (Skalar San++). Potassium was estimated using Flame Photometer (ELICO) and calcium and magnesium were estimated using an Atomic Absorption Spectrophotometer (VARIAN). Mass loss over time was computed using the negative exponential decay model (Olson, 1963). The time required for 50% (t50) and 99% (t99) decay was calculated as t50 = 0.693/k and t99 = 5/k. Nutrient content of the litter was calculated using the formula.

$$N = \left(\frac{C}{C_0}\right) \times \left(\frac{D_M}{D_{M0}}\right) \times 100$$

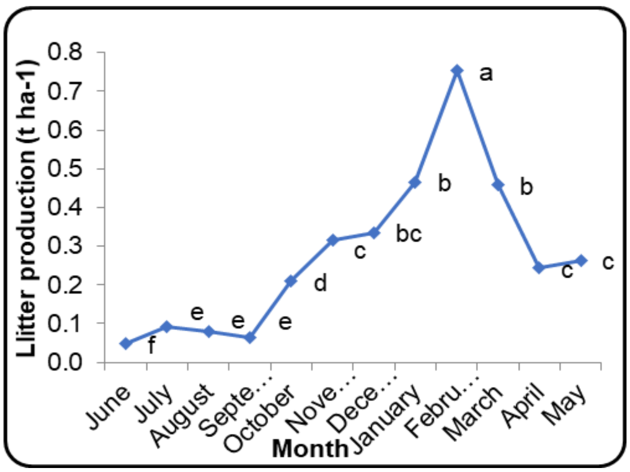

Figure 2: Litter production dynamics of *Thyrsostachys oliveri* during June, 2010 to May, 2011

Where, N is the percentage of nutrient remaining in the litter. C is the concentration of the element in litter at the time of sampling; C0 is the concentration of element in the initial litter kept for decomposition; DM is the mass of dry matter at the time of sampling and DM0 is the mass of initial dry matter kept for decomposition (Bockheim *et al*., 1991). The % nutrient release from the litter mass was calculated as 100 − N.

Statistical analysis

The data were subjected to one-way analysis of variance in SPSS 17 for windows and treatment means were compared using least significant difference (lsd) wherever necessary. Correlation and regression analysis also were carried out in SPSS 17. Litter decay constant was calculated using MS-Excel 2007.

Results and Discussion

The average clump and culm dimensions of the species at the time of observation were recorded. The individual clumps recorded 15.67±3.31 culms within a circumference of 1.43±0.17 m. The average height, girth at breast height, number of nodes and intermodal length of the culms were 12.37±1.44 m, 16.30±2.07 cm, and 58.85±6.84 and 13.46±1.54 cm, respectively.

Litter production

Total litter production of *T. oliveri* from June, 2010 to May, 2011 was 4.488 t ha^{-1} spread throughout the year with significant monthly variations (p=0.01). Although litter production was spread throughout the year, only very low quantity was recorded during the rainy season (June to September). Considerable litter accumulation of floor started from October onwards and it was at the peak during February. Litterfall showed a bimodal distribution pattern with a major peak during February, 2011 and a minor peak during July, 2010 (Figure 2). The major peak of February can be attributed to natural senescence of leaves induced by temperature and/or moisture stress in the region. When the litter production for different seasons was totaled, it showed profound variation with rainy season recording the lowest litterfall. More than three-fourths of the litterfall in *T. oliveri* occurred from November to March. Seasonal variation in litter accumulation pattern similar to our study has been observed in many studies (Ndakara, 2011; Toledo-Bruno *et al*., 2017; Devi and Singh, 2017). They reported an increase in monthly litter production during the dry season and a lower litter production in the wet season. Significant correlations obtained among climatic factors and litter production also support this. Litter production correlated with monthly rainfall (r= -0.74, p=0.01) and maximum (r= 0.79, p=0.01) temperature.

Litterfall quantification is important while estimating nutrient turnover, C and N fluxes, and C and N pools in ecosystems. Proctor (1987) reported that the litter accumulation of forest floor mass is usually low in moist tropical forests and in many ecosystems amounts to only 2 to 11 t ha^{-1}. Litter deposition in our study was near to the range reported by Proctor (1987). However, litter deposition of *T. oliveri* was lower compared to that of most tropical and sub-tropical bamboo species (Upadhyaya *et al*., 2008; Jagadish *et al*., 2015; Toledo-Bruno *et al*., 2017) whereas, litter deposition in the present study was greater than that reported for *Dendrocalamus strictus* (Joshi *et al*., 1991) and *Arundinaria racemosa* (Upadhyaya *et al*., 2008).

Proximate litter composition analysis indicated that major share of total litterfall in *T. oliveri* was contributed by leaves (93.60±0.99%) followed by branches (5.82±0.99%) and culm sheaths (0.76±0.75%). These results are in conformity with the pattern observed in bamboos and most other species of tropical forests (Ge *et al*., 2014, Toledo-Bruno *et al*., 2017; Devi and Singh, 2017). The annual input of nutrients to the soil through litterfall was deduced from the initial chemistry and total litter production (Figure 3). The annual input of nutrients to the soil via litter deposition in *T. oliveri* was in the order N =K> P>Ca >Mg. Literature indicated species-specific variation in the nutrient inputs through leaf litter. In *Dendrocalamus asper* the nutrient input was in the order: N > Ca > K > Mg >P (Toledo-Bruno *et al*. 2017). Nutrient addition in the present study are higher compared to that of *D. strictus* [N (29.3 kg ha^{-1}), P (1.05 kg ha^{-1}) and K (14.6 kg ha^{-1}), Tripathi and Singh, 1994] and Bambusa balcooa and B. vulgaris [N (16.06-22.68 kg ha^{-1}), P(1.74-2.65 kg ha^{-1}) and K (7.49-11.92 kg ha^{-1}), Nath and Das, 2012].

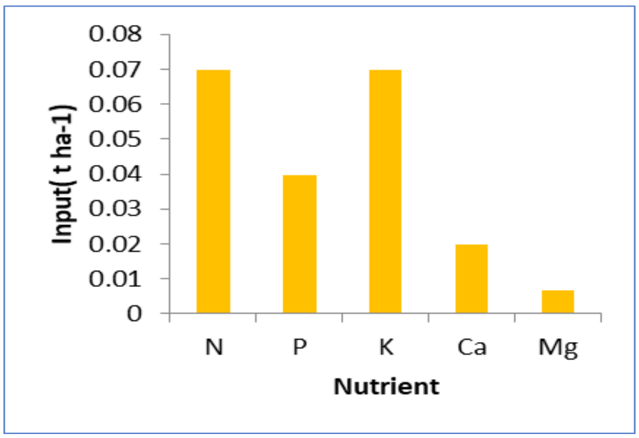

Figure 3: Nutrient inputs through annual litterfall of *Thyrsostachys oliveri*

Litter decomposition

Monthly litter decomposition pattern (Figure. 4) showed an initial rapid loss followed by a slower rate towards the end. Hence, a negative exponential model $y=e^{-kt}$ was fitted to the mass loss data. The rate of decomposition was a good fit to the exponential decay model suggested by Olson (1963). The regression model that depicted the progression of litter decomposition was $y = 90.87e^{-0.009t}$. (R^2=0.98) Decomposition rate constant was 0.009 g day^{-1} the half-life was 77 days and days taken for 99% decomposition was 556.

A three-phase decomposition pattern with initial slow phase, intermediate fast phase and terminal slow phase has been reported in litter incubated long before rainy season (Sujatha *et al*., 2003, Jagadish *et al*., 2015), whereas a two-phase pattern is observed in litter incubated at the beginning of rainy season (Nath and Das, 2012) especially in a monsoon climate. The two-phase pattern comprising an initial rapid phase followed by a slower phase obtained in the present study might be due to incubation of litter just before the rainy season. During litter decomposition, mass loss rates were higher during the initial period experiencing Southwest monsoon). During this phase, due to the rapid multiplication and intense activity of microbes most of the easily decomposable substances are lost from the system. The initial faster mass loss might be associated with the release of easily decomposable materials, as a result relatively more decay resistant materials remain in the litterbags and this might have caused a decrease in mass loss during the following months. The perusal of literature indicates that the bamboo litter decomposition rate varies with species and location. Generally, in moist deciduous and moist evergreen forests of the tropical environment, litter decomposition is completed within seven months and more or less one year in temperate deciduous forests. The monthly decomposition rate constant of *T. oliveri* (0.28) was higher compared to other bamboo species like *Ochlandra setigera* (0.23) (Thomas *et al*., 2014) and *O. travancorica* (0.23) situated natural forests of the southern Western Ghats of India (Sujatha *et al*., 2003) but lower compared to *B. balcooa* (0.35) and *O. travancorica* (0.45) established as plantations (Jijeesh and Seethalakshmi, 2016 a-b). The monthly decomposition rates of trees like *Ailanthus triphysa* (0.31), *Leucaena leucocephala* (0.29) grown under plantations or agroforestry systems were comparable with that of *T. oliveri*. Whereas that of *Artocarpus heterophyllus* (0.22) and *A. hirsutus* (0.21) were lower (Jamaludheen and Kumar, 1999) compared to present study. The decay rate constants in tropical plantations range between 0.11-2.00 (O'connell & Sankaran 1997) and the k value of *T. oliveri* falls within this range.

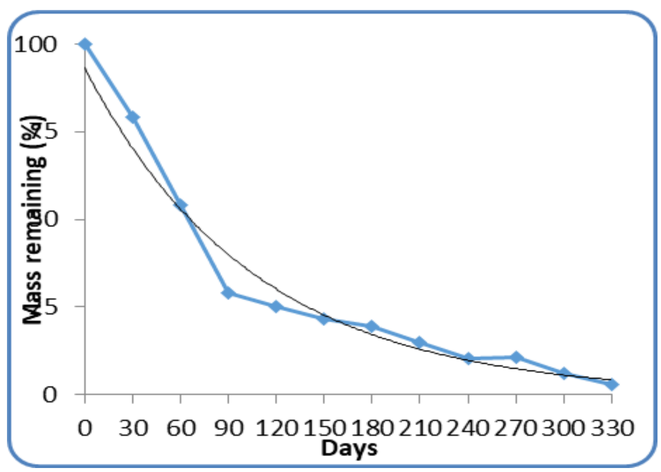

Figure 4: Litter decomposition of *Thyrsostachys oliveri* (Coloured line represents the actual weight loss and non-coloured denote predicted weight loss based on an exponential model

Initial litter chemistry

Initial litter quality plays a major role in the litter decomposition pattern (Nikolaidou, 2010). In *T. oliveri*, carbon was the major component followed by nitrogen and the nutrient in the least quantity was Mg (Table 2). The ratios of carbon to N, P and K also varied and the C: N ratio was 21.79. But a higher C: P and C: K was observed. Initial N and lower C: N ratio have been well correlated with the weight loss, a low C: N ratio can promote faster decomposition and vice versa. (Hobbie *et al*., 2008). The C: N ratio up to 20: 1 indicates a high mineralisation and subsequent nutrient release. Ge *et al*. (2014) had recorded lower carbon content in litterfall of moso bamboo (13%) compared to the present study.

Table 2: Initial litter chemistry of *Thyrsostachys oliveri*

Nutrients	Value
Nitrogen (%)	1.546±0.103[a]
Phosphorus (%)	0.796±0.066[a]
Potassium (%)	1.529±0.115[a]
Calcium (%)	0.469±0.095[ab]
Magnesium (%)	0.125±0.011[a]
Carbon (%)	33.56±0.76[a]
C: N ratio	21.79±1.83 [a]
C: P ratio	42.32±2.46 [a]
C: K ratio	22.05±1.84[bc]

Nutrient release

Concentration (%) of nutrients, N, P, K, Ca and Mg in the litter mass retrieved at monthly interval varied and nutrient content, in general, was lower towards the end of decomposition (Figure 5). Analysis of variance revealed a significant difference in all nutrient concentrations except K at the monthly intervals (p=0.01). The concentration of nitrogen in the decomposing litter mass ranged from 1.06 to 1.89 %. An initial decline in N concentration up to 150 days was observed followed by an increase and it remained constant during 240 to 270 days and again the N concentration declined. Phosphorus concentration in litter mass during incubation ranged from 0.796 to 0.077%. With a few exceptions, the P concentration of the decomposing litter mass declined with the period of incubation. The initial K concentration was 1.53%, which declined to 0.44% in June, 2010 (30 days). The K concentration increased steadily and reached the highest (1.60%) at 210 days and thereafter the K content of litter in decomposing litter mass declined. The calcium concentration in litter samples ranged from 0.469 to 0.117% at different stages of decomposition. Initial concentration was 0.469% which decreased to 0.125% in 120 days. It increased to 0.402% at 150 days and again decreased to 0.148% at December 2010 (210 days). Calcium concentration of litter mass increased slightly till February and thereafter, declined and the lowest concentration was observed in April 2011 (0.117%). The concentration of magnesium ranged from 0.256 to 0.077% at different stages of litter incubation. The initial Mg concentration of the litter was 0.125 % which decreased in June, 2010 and steadily increased and reached the maximum (0.256 %) in January, 2011 (240 days). Thereafter a decline in the Mg content of litter mass of *T. oliveri* was observed.

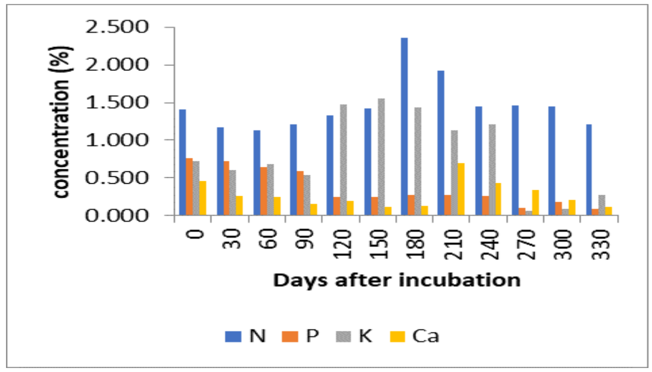

Figure 5: Nutrient concentrations in the monthly retrieved litter samples of *Thyrsostachys oliveri*

Nutrient release or accumulation during the decomposition process is due to of mineralization, leaching, consumption or transformation by soil biota (Isaac and Nair, 2006). The percentage of nutrient in the remaining litter of bamboo species at different stages of incubation is given in Figure. 6. In *T. oliveri*, the N remaining at 30 days was 72.67% which implied that 27.33% of N release occurred in first month. There was an accumulation phase at 180 days after incubation. More than 75% of the nitrogen in the litter mass of *T. oliveri* was released within 120 days. Usually, the decline in N is associated with loss of easily leachable components of litter mass. The increase in N after initial release is associated with microbial fixation of atmospheric N_2 inputs from external sources like throughfall and microbial immobilization (Laskowski *et al*., 1995).

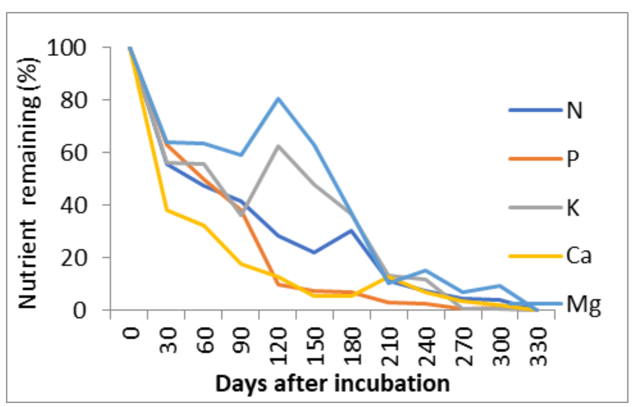

Figure 6: The percentage of nutrient in the remaining litter mass of *Thyrsostachys oliveri*

Meanwhile, P remaining at 30 days was 58.54% which implied that 41.46% P release occurred in first month and the P release continued till 150 days. There was a slight P accumulation phase at 180 days after incubation (0.72%) otherwise the nutrient release was continuous. Previous studies indicated that the concentration of P sometimes decreases or increases or remains constant during decomposition. This is a characteristic of the leaf litter quality and the site, mainly whether P is limited (Moore *et al*., 2006). Our results are inconsistent with those of Sujatha *et al*. (2003) for *O. travancorica* where an increase in P concentration was recorded during decomposition.

The K release in *T. oliveri* was faster; at the end of first month itself, 75.97% release occurred. There was only a K accumulation phase at 60 days after incubation with this exception the K release was continuous. Attiwill (1968) found K was the most mobile element and this explains the rapid release of this nutrient. In contrast to N and P, K is not bound as a structural component in plants and is highly water soluble. Meanwhile, at the end of 30 days, 24.44% of Ca release occurred. The highest release of Ca was observed at 90 days (35.46%). More than 80% of Ca was released within 90 days after incubation. There were three Ca accumulation phases at 150, 240 and 270 days after incubation. Attiwill (1968) had reported that the loss of calcium from decomposing litter was slow due to its importance as a structural component.

The Mg release in *T. oliveri*, at the end of first month of decomposition was 49.59%. During first 90 days, more than 70% Mg release occurred. There were two Mg accumulation phases at 120 and 180 days after incubation where 6.12 and 0.29% Mg accumulated in the litter mass. Many authors reported Mg dynamics in decomposing litter similar to the two-phase pattern recorded in our study (initial leaching phase and late immobilization phase (Hasegawam and Takeda, 1997). Magnesium is not a structural material and exists mainly in solution in plant cells and thus leached out from litter in the initial phase of decomposition.

Nutrient release rates were all rapid in the early stages of decomposition but slowed later. Hence, a negative exponential model was fitted ($y=e^{-kt}$). The relation between time and the rate of nutrient release was analyzed using regression analysis. The exponential regressions equation used to describe mass loss through time were significant (p = 0.01) and the k value, t50 and t 99 are given in Table 3. The nutrient release from the decomposing litter mass was in the order: Mg > N > Ca > P > K.

The Pearson's coefficient of correlation among mass loss and nutrient remaining (N, P, K, Ca and Mg) during litter decay and the mass loss during decomposition was determined. In *T. oliveri*, the mass loss significantly and very strongly correlated with Ca (r = 0.98) and N (r = 0.98) content. Litter mass loss was also correlated with remaining K (r = 0.82), Ca (r = 0.98) and Mg (r = 0.91).

Timing of litterfall and litter quality determine the contribution of litter to soil fertility through decomposition (Semwal *et al*., 2003). Decomposition studies indicated that the litter decomposes to half of its original mass within 80 days in and *T. oliveri*. Two phases of heavy litterfall occurred in this species, first during November to January and second during the summer season. The slow release of nutrients from litterfall in October-November may facilitate summer cropping in April, while the second peak in February makes nutrients available for monsoon cropping in July. Release pattern of major nutrients like N, P and K revealed that half-life of N release was 76 days that of P was 49 days and of K was 46 days. Higher litter mass loss during the rainy season enhances nutrient availability for monsoon crops. The release of more than 60 % of N in first month is good for intercrops in the initial phase of growth. Hence, intercropping may be initiated in *T. oliveri*. The nutrient release pattern of this species increases nutrient availability to crops, thereby resulting in considerable saving on external nutrient input costs and contribute to the overall sustainability of the system. Hence, this species can be incorporated into farmers' field.

Table 3: Exponential regression equations for nutrient release during litter decomposition of *Thyrsostachys oliveri*

Nutrient	Exponential Regression Equation	Coefficient of determination (R^2)	k ($month^{-1}$)	t_{50} (days)	t_{99} (days)
N	$y = 109.69e^{-0.2734x}$	0.91	0.273	76.0	548.6
P	$y = 125.31e^{-0.4293x}$	0.96	0.429	48.5	349.7
K	$y = 156.99e^{-0.4574x}$	0.69	0.457	45.5	327.9
Ca	$y = 94.889e^{-0.3264x}$	0.84	0.326	63.7	459.6
Mg	$y = 77.08e^{-0.1708x}$	0.81	0.171	121.7	878.2

Conclusion

Overall it can be concluded that the litter production in this species followed a bimodal distribution. Nutrient concentration in the monthly retrieved litter samples varied with the type of nutrient. Nutrient release from the litter was continuous with some exemption. It is recommended that litter dynamics studies are to be conducted before introduction of a bamboo species into degraded or marginal lands or agroforestry systems. Further studies with other bamboo species are required for the better understanding of nutrient requirement to introduce them into cultivation.

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