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Litterfall and decomposition dynamics of six year old *Bambusa balcooa* Roxb. homestead block plantation in Palakkad, central Kerala

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Abstract
The present study examined the litterfall, its decomposition and nutrient release dynamics of *Bambusa balcooa.* The litterfall and decomposition were estimated using standard techniques. The total annual litter production in this species was 4.06 4 t ha^{-1}. Litter production followed a biphasic pattern with a major peak in February 2011 and minor peak in December, 2010. The rate of decomposition in *B. balcooa* litter was a good fit to exponential decay model. The decomposition rate constant of *B. balcooa* was 0.0115 day^{-1} and the half-life was 77 days. Litterfall and decomposition was influenced by the climatic factors like maximum temperature and rainfall. The release of nutrients from the decomposing litter was in the order Mg > N > Ca > P > K.

Keywords: *Bambusa balcooa*, Decomposition rate, Litter decomposition, Litterfall, Nutrient release

Introduction
Bamboo is a fast-growing arborescent grasses belongs to the family *Poaceae*, subfamily *Bambusoideae*, tribe *Bambuseae*. It is known as “Green Gold” because of its faster growth and multifarious uses. Bamboo, which occurs in almost all the states of India, has been used as a cattle fodder and its seasons for palatability and digestibility depending on species (Antwi-Boasiako *et al*., 2011; Devi, 2013). Fresh bamboo leaves can be collected throughout the year owing to its evergreen nature. Dixit *et al.* (2015) reported that, at country level, area under permanent pastures and grasslands has declined from 120 to 102 lakh hectares during 1980-81 to 2007-08. Hence, the green gold can be an alternate option to satiate the fodder demand. Indeed, the leaves are being used as emergency fodder for animals, especially during floods in West Bengal and Bihar (Banik, 2016).

B. balcooa is indigenous to the North-East India, Bihar, Jharkhand, Uttaranchal, West Bengal and Bangladesh. It was introduced to Kerala owing to its non-thorny nature and strength properties. Besides fodder, the most common use of this sturdy and strong bamboo is in construction, thatching, walling, roofing, handicrafts and for making novelty items. It is good for scaffolding, making ladders, pulp, paper, rayon and agarbathi sticks (Seethalakshmi and Kumar, 1998). The young shoots are quite popular as vegetable food. Due to its multifarious uses, it is identified as one of the priority species for large scale cultivation in India by National Mission on Bamboo Applications and included among 38 species for international action (Rao and Rao, 1986).

Nowadays, bamboo based agroforestry systems are becoming popular in our country and the species like *Bambusa balcooa*, *B. bambos, B. vulgaris, Dendrocalamus strictus* and *D. hamiltonii* have been incorporated into different agroforestry systems in Kerala and north-eastern states of India (Chandrashekara *et al.*, 1997; Viswanath *et al.*, 2007). In Kerala, home gardens contribute 63% of the total supply of bamboo and the remaining 37% is contributed by forests (Krishnankutty, 1998). More and more farmers are attracted towards bamboo cultivation due to its faster growth and biomass production. Prior to introduction of bamboos to farmer’s field, it is imperative to study litter production, decomposition and nutrient release dynamics in order to explore the possibility of intercropping and make fertilizer recommendations.

Materials and Methods
Study area: The present study was conducted at Vilayannur (N 10° 37’58.7" and E 76°30’ 54.2’’), Palakkad district of Kerala, India from July 2010 to May 2011. The rainfall, relative humidity and maximum and minimum temperature of the study area is shown in Fig 1. *B. balcooa* plots were established in a progressive farmers’ field as block plantation in 2005 as part of the Multi-locational Bamboo Species Trial supported by National Mission on Bamboo Applications (Raveendran *et al.*, 2011).

Methods: Litterfall of *B. balcooa* was captured at monthly intervals using the specially designed litter traps made of bamboo baskets with diameter of 1 m and depth 10 cm placed in three sample plots. The litter traps were kept in the middle of the four bamboo clumps of the plot which were planted at a spacing of 5x5 m and were fixed 25 cm above ground using wooden pegs. Monthly litter fall was estimated up to one year. Litter decomposition study of *B. balcooa* was carried out by adopting standard litterbag techniques (Bocock and Gilbert, 1957).The freshly abscised bamboo litter was collected during the peak litter fall period (February-March 2010). The contribution of leaves, branches and culm sheaths to total litterfall was determined from the samples (500g x 5). Air dried litter mass weighing 25 g was 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 *B. balcooa* on first week of June 2010 on the surface of the soil. 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.

To determine the initial litter chemistry and chemistry of litter retrieved at each sampling period, litter samples were ground in a Wiley mill for analysis. Total carbon and nitrogen was estimated using Euro vector (EA 3000) CHNS Elementar analyser and phosphorus by using Skalar San++ Auto analyzer. Potassium was estimated using a flame photometer (ELICO) and calcium and magnesium using an Atomic Absorption Spectrophotometer (VARIAN) (Jackson, 1973). Mass loss over time was computed using the negative exponential decay model (Olson, 1963). The time required for 50% (t_{50}) and 99% (t_{99}) decay was calculated as t_{50} = 0.693/k and t_{99} = 5/k. Percent nutrient remaining in the litters was calculated using the formula.

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

where, N is percentage of nutrient remaining in the litter. C is the concentration of the element in litter at the time of sampling (%); C_0 is the concentration of element in the initial litter kept for decomposition (%); D_M is the mass of dry matter at the time of sampling (g) and D_{M0} is the mass of initial dry matter kept for decomposition (g) (Bockheim *et al.*, 1991). The percent 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) as necessary. Correlation and regression analysis also were carried out in SPSS 17. Litter decay constant was calculated using MS-Excel 2007.

Results and Discussion

Litterfall pattern: The total litterfall of *B. balcooa* from June 2010 to May 2011 was 4.064 t ha^{-1} spread throughout the year with significant (P=0.01) monthly variations (Fig. 1). Litterfall followed a bimodal distribution pattern with a major peak during February which might be associated with natural senescence of leaves induced by temperature and/or moisture stress in the region (Kumar and Deepu, 1992). Litter production indicated profound seasonal variation with rainy season recording the lowest litterfall. More than 70% of the litterfall *in B. balcooa* occurred during November to March*. S*easonal variation in litter accumulation pattern similar to our study was observed in many studies (Pragasan and Parthasarathy, 2005; Bhat *et al.* 2009; Soni *et al*. 2013). They reported an increase in monthly litter production during the dry season and a lower litter production in the wet season. Litter production of *B. balcooa* was correlated with climatic factors like monthly maximum temperature (r= 0.71, P=0.01) and minimum temperature (r= -0.41, P=0.05) and rainfall (r= -0.71, P=0.01).

Quantification of litter production 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 topical forests and in many ecosystems amounts to only 2 to 11 t ha^{-1}. Litterfall in our study was lower as compared to that of most tropical and sub-tropical bamboo species (Shanmughavel and Francis, 1996; Upadhyaya *et al.,* 2008) 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).

The data on proximate composition of litter indicated that the major share of total litter fall of *B. balcooa* was contributed by leaves (94.14±1.02%) followed by branches (4.36±0.96%) and culm sheaths (1.50±0.41%). The annual inputs of nutrients to the soil via litter deposition (t ha^{-1}) in *B. balcooa* were in the order N (0.06) > P (0.03) =K (0.03) Ca (0.02) >Mg (0.003).

Litter decomposition: Mass loss (dry weight basis) during litter decomposition of *B. balcooa* (Fig. 2) showed an initial rapid loss followed by 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 exponential decay model suggested by Olson (1963). The regression model that depicted the progression of litter decomposition was $y = 112.70e^{-0.0115t.}$ (R^2=0.98) decomposition rate constant was 0.0115 g day^{-1}, the half-life was 77 days and days taken for 99% decomposition was 556. Litter decomposition was correlated with climatic factors as reported by earlier workers (Kaushal *et al*., 2012) and the correlation coefficients were -0.74** (maximum temperature) and 0.75** (rainfall).

Generally, a three phase decomposition pattern (initial slow phase, intermediate fast phase and terminal slow phase) in litter incubated long before rainy season (Semwal *et al.*, 2003; Sujatha *et al.*, 2003) and two-phase pattern in litter incubated in the beginning of rainy season (Soni *et al.,* 2013) were observed in studies especially in a monsoon climate. A two phase pattern of litter decomposition comprising an initial rapid phase followed by a slower phase was obtained in the present study as the litter was incubated just before rainy season. During litter decomposition, mass loss rates were higher during the initial periods (during southwest monsoon), due to the rapid multiplication and intense activity of microbes as a result most of the easily decomposable substances are lost from the system (Palm and Rowland, 1997). 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 probably caused a decrease of mass loss during the following months. Perusal of literature indicates that the decomposition rate varies with bamboo species and location of the study. Singh and Singh (1999) reported 235 days for 50% and more than 1000 days for 95% decomposition in *Dendrocalamus strictus* plantation at Singrauli coal field of Madhya Pradesh. Studies revealed that in moist deciduous and moist evergreen forests in tropical environment, litter decomposed completely within seven months and more or less one year in temperate deciduous forests. The monthly decomposition rate constant of *B. balcooa* (0.34) was higher compared to *Ochlandra setigera* (0.23) at Nilambur (Thomas *et al.,* 2014) and *O. travancorica* (0.23) in Vazhachal of Thrissur district situated in the southern Western Ghats of India (Sujatha *et al.,* 2003). The *k* values worked out at the end of the decomposition in the present study corroborated with this range. Initial nutrient chemistry of the litter mass of Bambusa *balcooa* was studied (Table 1). Among the nutrients, carbon was the major component followed by nitrogen and the nutrient in least quantity was Mg. The ratios of carbon to N, P and K also varied and the C: N ratio was as low as 18.82. 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. The C:N ratio upto 20: 1 indicated a high mineralisation and subsequent nutrient release.

Table 1. Initial nutrient chemistry of litter in *Bambusa balcooa*

Nutrients	Value
Nitrogen (%)	1.409±0.037
Phosphorus (%)	0.757±0.071
Potassium (%)	0.716±0.016
Calcium (%)	0.453±0.009
Magnesium (%)	0.086±0.002
Carbon (%)	26.50±1.14
C: N ratio	18.82±0.86
C: P ratio	35.28±4.69
C: K ratio	37.04±2.22

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 (Fig. 3). In general, nitrogen concentration of *B. balcooa* ranged from 1.22–2.35%. The initial N content in the litter mass was 1.41% which decreased till 90 days after incubation (1.21%), increased slightly till 150 days and reached the maximum at 180 days of decomposition (2.35%). Thereafter, it decreased and remained constant as initial N concentration and the lowest value (1.22%) was obtained during April 2011 (at 330 days). Meanwhile, the initial P concentration was 0.757%. The P concentration declined steadily till September, 2010 (120^{th} day) and in the subsequent months there was a slight increase in P till 240 days. The P concentration was as low as 0.087% during April 2011 at 330 days. The concentration of K ranged from 0.06 to 1.55% at different stages of decomposition. The initial concentration of potassium was 0.72%. The K concentration of the litter, decreased steadily compared to initial concentration till August 2010 (90 days). During September (120 days) the concentration almost doubled and reached maximum value (1.55%) in October 2010 at 150 days. Thereafter, the K concentration of litter samples

Table 2. Exponential regression equations for nutrient release during litter decomposition of *B. balcooa*

Nutrient	Exponential regression equation	Coefficient of determination (R^2)	K_N	t_{50N}	t_{99N}
N	$y = 137.28e^{-0.3164x}$	0.94	0.316	65.7	474.1
P	$y = 193.09e^{-0.5156x}$	0.96	0.516	40.4	291.3
K	$y = 322.17e^{-0.4904x}$	0.71	0.490	42.4	305.9
Ca	$y = 82.269e^{-0.3317x}$	0.86	0.332	62.7	452.2
Mg	$y = 161.92e^{-0.2673x}$	0.81	0.267	77.8	561.2

Where K_N is nutrient release constants, t_{50N} is time taken for 50% nutrient release and t_{99N} is time taken for 99% nutrient release

decreased to reach the lowest value (0.06%) at 270 days. A slight increase in K concentration compared to that at 270 days was observed during 300-330 days after incubation. The calcium concentration of the litter mass in *B. balcooa* ranged from 0.695 to 0.114% at different stages of decomposition. The initial Ca concentration was 0.453% in *B. balcooa* and it decreased during 30-180 days of incubation. The highest concentration of Ca in the litter mass was observed at 210 days (0.695%) and thereafter it declined. The magnesium concentration in litter mass of *B. balcooa* ranged from 0.246 to 0.083% at different stages of decomposition. The initial magnesium concentration was 0.086% which steadily increased and reached peak value (0.246%) at the end of 150 days. Thereafter, it decreased till 270 days. In March, 2011 (300 days) the Mg concentration in litter mass was 0.224%, which again dropped in April.

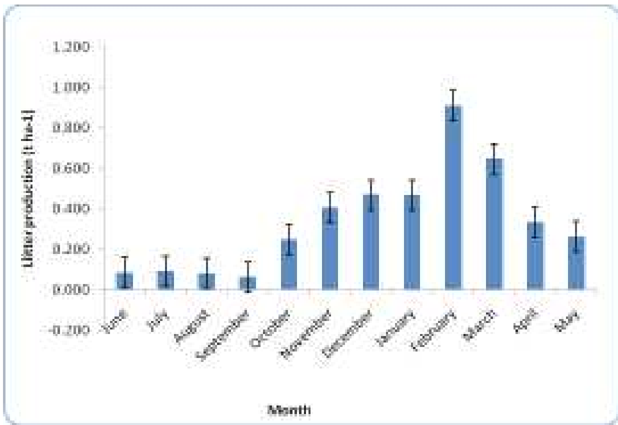

Fig 1. Litter production of *B. balcooa* during June 2010-May 2011

The percentage of nutrient in the remaining litter of bamboo species at different stages of incubation is given in figure 4. The figure depicts that the nitrogen content at the end of first month after incubation was 55.42% which implied, 44.52% N release occurred in the first month itself and it was the highest among the release of all periods. At 180 days after incubation, there was an accumulation phase in which 8.21% of N was accumulated in the litter mass.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 (Soni *et al.*, 2016). While, the P remaining in decomposing litter mass of *B. balcooa*, at 30 days of incubation was 62.98% of initial which indicated that the phosphorus release during this period was 37.02% and it was the highest among all periods. The second highest P release occurred at 120 days after incubation where 28.38% more release occurred. The P release was more or less continuous. Literature indicates 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, namely

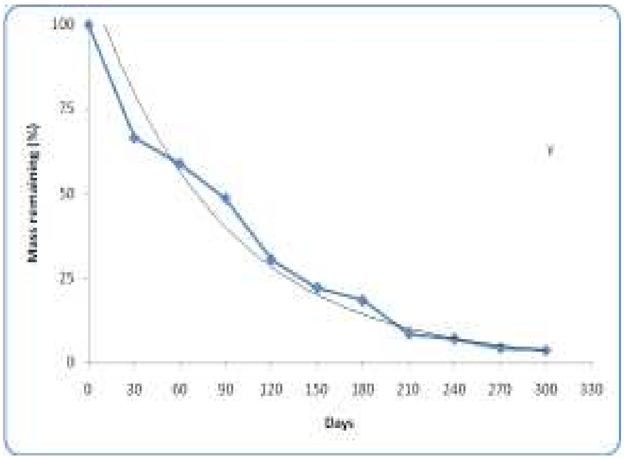

Fig 2. Pattern of litter decomposition of *Bambusa balcooa* (dark line represents the actual weight loss and dotted line denotes predicted weight loss based on an exponential model)

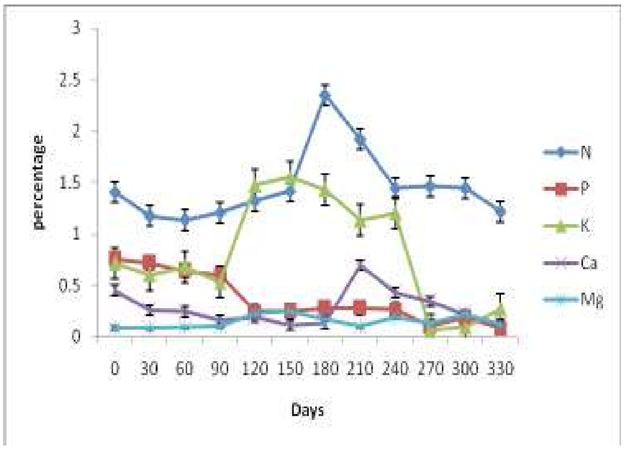

Fig 3. Nutrient concentrations in the monthly retrieved litter samples of *Bambusa balcooa*

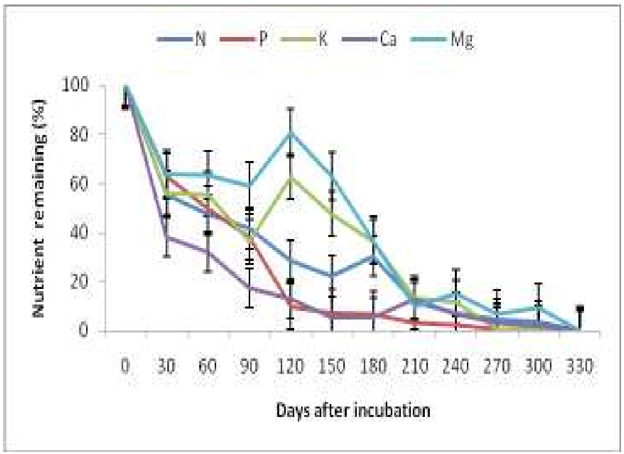

Fig 4. Nutrient percentage in the remaining litter mass of *Bambusa balcooa*

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 potassium content at June, 2010 (30 days) was 66.00% indicating the highest release of 34.00%, followed by 23.15% at 210 days. There was a major accumulation phase at 120 days after incubation where 26.41% of K was accumulated in the litter. The lowest release of K was observed at 60 days (0.38%). More than half of the K release from the litter mass occurred within 90 days due to its mobile nature 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. With some exception the release of Ca from the decomposing litter was continuous. More than 39% of the Ca release occurred during first month of incubation which was followed by 14.59% at 90 days after incubation. More than three-fourth of the Ca release in litter mass of *B. balcooa* occurred within 90 days of incubation. The magnesium released from the liter mass at 30 days after incubation was 36.01% and the second highest release was 26.86% at 210 days. The release of Mg was followed by an accumulation phase (21.74%) at 120 days. After the accumulation phase, during 150-180 days, 70% of Mg release occurred. There were two minor accumulation phases at 240 and 300 days after incubation where 5.28 and 2.64% of Mg accumulated to the litter samples. 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). The equations are given in Table 2. 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 positively and strongly correlated with nitrogen and phosphorus, remaining in the litter samples. In *B. balcooa* the mass loss was also significantly and strongly correlated with N (r = 0.98) and P (r = 0.98) content.

Conclusion

Litter quality and the timing of litterfall determine the contribution of leaf litter of agroforestry trees to soil fertility through decomposition (Semwal *et al.,* 2003). In the present study, two phases of heavy litterfall occurred, first during November to January and second during the summer season. Decomposition studies indicated that the litter decomposes to half of its original mass within 80 days in *B. balcooa*. Hence, the slow release of nutrients from litterfall in October-November may facilitate summer cropping, while the second peak in February makes nutrients available for monsoon cropping. Release pattern of major nutrients like N, P and K revealed that more than 44% of N release occurred within 30 days, 50% of P release occurred within 60 days and more than 40% of K released during first month. Higher litter weight loss during the rainy season enhances nutrient availability for monsoon crops. The release of more than 44% of N in first month is good for intercrops in the initial phase of growth. Hence, intercropping may be initiated in *B. balcooa*. The nutrient release pattern of this species augment nutrient availability to crops, thereby affecting considerable saving on external nutrient input costs and contribute to the overall sustainability of the system. Hence, this species can be incorporated into farmer's field. The litter production was continuous in this species and the evergreen nature of this species can contribute fodder during all the period.

In nutshell, the study indicated that litter production in this species was continuous and followed a bimodal distribution. Litter decomposition was good fit to the exponential model. Nutrient concentration in the monthly retrieved litter samples varied with the type of nutrient. Nutrient release from the litter was more or less continuous with some exemption.

References

Antwi-Boasiako C., G. Y. Coffie and N. A. Darkwa. 2011. Proximate composition of the leaves of *Bambusa ventricosa, Oxytenanthera abyssinica* and two varieties of *Bambusa vulgaris*. *Scientific Research and Essays* 6: 6835-6839.

Banik, R. L. 2016. *Silviculture of South Asian Priority Bamboos*. Springer, Singapore pp. 25.

Bhat, N., R. Verma and Z. Reshi. 2009. Seasonal variation of litter Production in *Fraxinus excelsior* Linn. and *Ulmus villosa* Brandis in forests of Dachigam national park (J&K). *Indian Forester* 135: 825-830.

Bockheim, J. G., E. A. Jepson and D. M. Helsey. 1991. Nutrient dynamics in decomposing leaf litter of four tree species in northern Wisconsin. *Canadian Journal of Forest Research* 21: 267–286.

Bocock, K. L. and O. J. W. Gilbert. 1957. The disappearance of leaf litter under different woodland conditions. *Plant and Soil* 9: 179–185.

Chandrashekara, U. M., S. Sankar and R. Ganaharan. 1997. *Socio-economic and ecological aspects of developing bamboo resources in homesteads of kerala.: Ecological and social aspects*. KFRI Research Report No. 125 Part 1. Kerala Forest Research Institute, Peechi.

Devi, Y. R. 2013. Bamboo forest resources of India and its role in food security - a review *Agricultural Reviews* 34: 236-241.

Dixit, A. K., M. K. Singh, A. K. Roy, B. S. Reddy and Narendra Singh. 2015. Trends and contribution of grazing resources to livestock in different states of India. *Range Management and Agroforestry* 36**:** 204-210.

Hasegawam, M. and H. Takeda. 1997. Carbon and nutrient dynamics in decomposing pine needle litter in relation to fungal and faunal abundances. *Pedobiologia* 40: 171–184.

Jackson, M. L. 1973. *Soil Chemical Analysis*. Prentice Hall of Englewood cliffs, New Jersey, USA.

Joshi, A. P., R. C. Sundrial and D. C. Baluni. 1991. Nutrient dynamics of lower siwalik bamboo forest in the Garhwal Himalaya. *Journal of Tropical Forest Science* 3: 338-350.

Kaushal, R., K. S. Verma, O. P. Chaturvedi and N. M. Alam. 2012. Leaf litter decomposition and nutrient dynamics in four multipurpose tree species. *Range Management and Agroforestry* 33: 20-27.

Krishnankutty, C. N. 1998. *Socio-economic and ecological aspects of developing bamboo resources in homesteads of Kerala. Part 2:Economic and management aspects*. KFRI Research Report No. 125. Kerala Forest Research Institute, Peechi.

Kumar, B. M. and J. K. Deepu. 1992. Litter production and decomposition dynamics in moist deciduous forests of the Western Ghats in Peninsular India, *Forest Ecology and Manag*ement 50**:** 181-201.

Moore, T. R., J. A. Trofymow, C.E. Prescott, J. Fyles and B. D. Titus. 2006. Patterns of carbon, nitrogen and phosphorus dynamics in decomposing foliar litter in Canadian forests. *Ecosystems* 9: 46–62.

Olson, J. S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. *Ecology* 44: 322-331.

Palm, C. A. and A. P. Rowland.1997. A minimum dataset for characterization of plant quality for decomposition. In: G. Cadish, and K. E. Giller (eds). *Driven by Nature: Plant Litter Quality and Decomposition*. CAB International, London. pp. 379–392.

Pragasan, A. and N. Parthasarathy. 2005. Litter production in tropical dry evergreen forests of south India in relation to season, plant life-forms and physiognomic groups. *Current Science* 88: 1255-1263.

Rao, A. N. and V. R. Rao. 1998. *Priority Species of Bamboo and Rattan*. IPGRI-APO, Serdang, Malaysia.

Raveendran, V. P., K. K. Seethalakshmi, and K. K. Unni. 2011. *Multilocational field trials for selected bamboo species.* KFRI Research Report, Kerala Forest Research Institute, Peechi.

Seethalakshmi, K. K. and M. S. Kumar. 1998. *Bamboos of India- a compendium*. Kerala Forest Research Institute, Peechi and International Network for Bamboo and Rattan, New Delhi.

Semwal, R. L., R. K. Maikhur, K. S. Rao, K. K. Sen and K. G. Saxena. 2003. Leaf litter decomposition and nutrient release patterns of six multipurpose tree species of central Himalaya, India. *Biomass and Bioenergy* 24: 3–11.

Shanmughavel, P. and K. Francis. 1996. Biomass and nutrient cycling in bamboo (*Bambusa bambos*) plantations of tropical areas. *Biology and Fertility of Soils* 23: 431-434.

Singh, A. N and J. S. Singh. 1999: Biomass, net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region. *Forest Ecology and Management* 119: 195-207.

Soni, M. L., N. D. Yadava and S. Bhardwaj. 2013. Decompositionand nitrogen release dynamics of fruit tree leaf litters in arid western Rajasthan. *Annals of Arid Zone* 52:31-37.

Soni, M. L., N. D. Yadava and S. Bhardwaj. 2016. Dynamics of leaf litter decomposition of four tree species of arid western Rajasthan under varying soil moisture regimes. *International Journal of Tropical Agriculture* 34: 955-960.

Sujatha, M. P., A. I. Jose and S. Sankar. 2003. Leaf litter decomposition and nutrient release in reed bamboo (*Ochlandra travancorica*). *Journal of Bamboo and Rattan* 2: 65-78.

Thomas K., C. M. Jijeesh, and K. K. Seethalakshmi. 2014. Litter production, decomposition and nutrient mineralization dynamics of *Ochlandra setigera*: A rare bamboo species of Nilgiri Biosphere Reserve, India. *Journal of Forestry Research* 25: 579"584.

Upadhyaya, K., A. Arunachalam., K. Arunachalam and A.K. Das. 2008. Above ground biomass and productivity appraisal of four important bamboo species growing along different altitudinal regimes in Arunachal Pradesh. *Journal of Bamboo and Rattan* 7: 219-234.

Viswanath, S., B. Dhanya and T. S. Rathore. 2007. Domestication of *Dendrocalamus brandisii* in upland paddy fields in Coorg, Karnataka. *Journal of Bamboo and Rattan* 6**:** 215-222.