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ECOLOGICAL STUDIES ON BAMBUSA ARUNDINACEA (RETZ.) WILLD. GROWING IN TEAK PLANTATIONS OF KERALA, INDIA

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ABSTRACT

A study was undertaken to assess the contribution of bamboo to the vegetation structure, biomass productivity and nutrient cycling pattern in 15 to 20- yr old teak plantations of Kariem-muriem Forest Range, Kerala, India. Based on the distribution pattern of bamboo colonised in these plantations three site types were recognised and they are: Site type A (bamboo rich area), Site type B (moderately bamboo rich area) and Site type C (bamboo poor area). Density, basal area, number of culms per ha, biomass, litter and net primary production of bamboo were more in Site type A than in Site types B and C. While the soils of Site types A and B were rich in potassium, those of Site type C were rich in calcium content. In addition to this, a negative correlation between above-ground biomass of bamboo and teak was recorded in Site type A. In the case of teak, the rate of accumulation and enrichment ratio of calcium were more than those of other elements. On the other hand, in bamboo, the enrichment ratio and accumulation rate of potassium were higher than in teak. The values for the above parameters in bamboo were higher for potassium than for other elements. These results show that even from the nutrient conservation and cycling point of view bamboo is the suitable species for Site type A and teak for Site types C and B. It is recommended that inter-planting of bamboo in teak plantation, especially in areas like Site types B and C is not advisable. Instead, patch-planting may be more appropriate both to get better yield and to maintain the ecosystem stability. It is also concluded that management of key elements such as potassium of the ecosystem, after disturbance or conversion of natural forests into plantations, is crucial for the stability of the ecosystem.

1. INTRODUCTION

In Kerala, teak plantations occupy around 80,000 ha which comes nearly 51% of the area in the State under plantations (Kerala Forest Department, 1990). Most of these plantations are of quality III (41%) followed by those of quality II (48%) (Jayaraman, 1995). It has been reported that the teak plantations of quality III and II are often recolonised or invaded by *Bambusa arundinacea* or some other species of bamboo (FAO, 1956). Even in teak plantations of good site quality, quite often invasion of bamboo in water-logged areas and areas bordering swamps are seen (Browne, 1928). Thus bamboo is one of the plant components in several teak plantations as those in Kerala State in India. However, the distribution of bamboo may not be uniform in such plantations. Though bamboo of these teak plantations of most of the Forest Divisions are being extracted on commercial scale at frequent intervals, so far no attempt has been made to understand the distribution pattern of bamboo in a given teak plantation and the contribution of bamboos in vegetation composition, biomass production and nutrient cycling in such plantations. While the studies on biomass are essential for estimating net primary productivity, those of nutrient cycling help in assessing the stability of ecosystem and nutrient mobilization and conservation process. Furthermore, quantitative knowledge of the structural and functional patterns i.e. density, basal cover, biomass, net productivity and nutrient cycling by the component species in man-made ecosystems is a basic requisite for silvicultural decision-making. In addition to this, information on differing ecological requirements and growth characteristics and thus the intensity of interspecific competition between the component species will also help to design appropriate planting techniques. Thus the main objectives of this study was to understand the distribution pattern of bamboos in teak plantations and to study the vegetation structure, biomass, productivity and nutrient cycling with particular reference to the contribution of bamboo to the above mentioned parameters.

2. STUDY AREA AND CLIMATE

Two teak plantations of years 15 and 20 years of located in the Kariem-muriem reserve (11°17'- 11°23'N, and 76°16'- 76°18'E) of the Nilambur Forest Division were selected for the study. All the three plantations are at an altitude between 100-150 m above mean sea level with south or south-easterly aspect and eastern or southern side slope. The underlying rocks are laterite and the soil is sandy loam. The distance between plantations varied from 0.5 to 4.0 km.

The climate is typically monsoonic with an average rainfall of over 2500 mm. The major portion (70 %) of the annual rainfall occurs from the south-west monsoon, which starts from the early of June and continues till the end of August. The north-east monsoon which sets in October and lasts till the end of November gives but comparatively less quantity of rainfall. The mean annual maximum temperature is 35°C and the mean annual minimum is 15°C.

The natural forests of the area were of tropical moist deciduous type and tree species predominant were *Terminalia crenulata* Roth, *Terminaliapaniculata* Roth, *Lagerstroemia microcarpa* Wt. and *Xylia xylocarpa* (Roxb.) Taub. *Bambusa arundinacea* (Retz.) Willd., *Calycopterisfloribunda* Lam. and *Helicteres isora* L. were the important undergrowth species. In teak plantations, seedlings, saplings and few mature individuals of miscellaneous tree species such as *Bombax ceiba* L., *Dalbergia latifolia* Roxb., *Gmelina arborea* Roxb., *Mallotus tetracoccus* (Roxb.) Kurz, *Terminalia paniculata* Roth., and *Xylia xylocarpa* (Roxb.) Taub. and shrubs such as *Chromolaena odorata* (L.) King and Robin, *Clerodendrum viscosum* Vent., *Helicteres isora* L. and *Leea indica* (Burm.f.) Merr. and herbs such as *Amomom cannaecarpum* (Wt.) Benth., *Crotolaria filipes* Benth., *Cynodon dactylon* (L.) Pers., *Oldenlandia caerulea* Benth and *Triumfetta rotundifolia* Lamk. are seen.

3. METHODS

3.1 Site selection

Preliminary visits made in above mentioned teak plantations showed variation in terms of distribution and density of bamboo clumps within each plantation. While more bamboo clumps were observed near the swampy areas less clumps were seen on the upward slpes of these plantations. Thus it was decided to quantitively analyse bamboo clump distribution and clump size at different distance from the water course. In each plantation, three quadrats, each of 300 m long and 100 m wide, were marked along a transect so as to cover both the swampy areas and upward slope area. The distance between two transects was 200-300m. The slope of the plots varied between 8% and 15% and the maximum elevation recorded at the upward slope area was 32 m and minimum recorded at the swamp bottom was 2 m from the nearby stream The distance between the stream and the edge of the plantation varied between 2 and 5.2 m. Each quadrat was further sub-divided into 20x20 m plots and in each such plot the total number of bamboo clumps and culms were recorded. Mean values thus obtained for clump density and size for the plots at different distances from the stream were compared to determine the pattern of distribution of bamboo clumps and culms. Based on the results obtained, the following three arbitrary but convenient classes of bamboo distribution were recognised.

Type A: plots having 3 or more clumps per 400 m^2 and each culm with more than 20 culms,

Type B: plots having 1-3 clumps per 400 m^2 and each clump with 10-19 culms, and

Type C: plots having 0-3 clumps per 400 m^2 and if clumps present each with less than 9 culms.

It was observed that highest number (83-100%) of plots (each of 400 m^2) with the first type of bamboo distribution were within 100 m distance from the edge of the plantation bordering the nearest stream or swamp whereas 72-100% of plots with the second type of bamboo distribution occurred between 120-200 m from the edge of the plantation. Beyond 220 m, 72-100% plots studied were of third type i.e., either without bamboo or with 1-3 clumps and each clump is with less than 9 culms. For each Site type, three replicate plots each of 1 ha area were demarcated to carry out detailed analysis.

3.2 Vegetation analysis

Phytosociological studies were carried out for herbs, shrubs, tree seedlings, saplings following standard methods (Kershaw, 1973). Vegetation analysis of herbs was based on twenty five 1 m x 1 m quadrats, while that of shrubs and tree seedlings was based on five 5 m x 5 m quadrats. Tree saplings were studied using ten 10 m x 10 m quadrats. Bamboo, teak and mature individuals of miscellaneous tree species were studied by lying out eight 25 m x 25 m quadrats. Species diversity in herbs, shrubs, tree seedlings and saplings and mature trees of miscellaneous species was calculated using the formula given by Shannon and Wienner (1963).

$$H = - [(ni/N)\log(ni/N)]$$

Where, H is the Shannon index of general diversity, ni, is the importance value index of each species, and N is the total importance value index of all species.

However, for bamboos and teak only the density, basal area and percentage frequency were calculated. In the case of bamboo, the number of culms per hectare was also estimated.

3.3 Estimation of Biomass

In case of teak, the biomass was measured through a non- destructive volume estimation method. Twenty four trees (eight each of 15, 16 and 20 years o1d)were randomly selected over the entire girth range and their height and girth at breast height (at 1.37 m above the ground level) were measured. The girth at breast height (GBH) value was considered to be the mean circumference of the bottom 2.74 m sector of the bole. Beyond the bottom sector, depending upon the tree height, the mid circumferences were measured in successive 3-to 5-m sectors. Sector volumes (V) were calculated by converting the girth to radius, and then calculating the volume as, $V = r^2 1$, where r and are mid-radius and length of the sector, respectively. Volumes of all sectors were summed to estimate the total bole volume. The specific gravity value given in Nazma *et al*. (1981) for teak wood was multiplied with the total wood volume .to obtain the bole biomass. The bole biomass values were regressed against the corresponding GBH values

The total number of the first-order branches in individual trees was recorded. From each tree three branches (representing,smal1,medium and large ones) were randomly selected. cut and weighed fresh. Small samples were removed from different branch sizes and dried at 80^{o} C. The branch biomass per tree was calculated by multiplying their total number with the mean branch dry weight. A regression model for GBH and total branch weight was prepared.

The total number of second-order branches were recorded for each of the three branches selected. Randomly, three branches were selected and counted the number of leaves present. Thus leaf biomass were estimated for the second-order branch as the product of leaf number and individual leaf weight. The total leaf biomass of the tree was estimated as the product of leaf biomass in second order branches and number of secondary branch in the tree.

Through the girth/biomass regressions the mean bole and branch weights were determined in each girth class. The number of trees in each girth class was multiplied by the corresponding mean tree biomass, and the computed biomass of all girth classes was summed to derive the stand biomass.

Biomass estimation in bamboo was based on a destructive method and some of the bamboo culms which had been marked in these plantations for felling were used for the purpose. On the basis of culm colour and presence or absence leaf sheath (Khan, 1962), the bamboo culms were classified into four age groups, namely 1-, 2-, 3-and more than 3 years old culms. Five bamboo culms for a given age group were randomly selected to represent each of the five girth classes. Thus totally twenty five culms were selected as destructive samples for every age group. The girth at breast height (GBH) value and total length of the culm was recorded. Immediately after felling, the fresh weights of foliage, branches and culms were determined individually. Sub-samples were brought to the laboratory for oven-drying at 80°C. Simple regression equations were developed between the weights of foliage, branches, culms and above-ground parts and d^2h for each age group

Through the girth/biomass regressions the mean culm and branch and foliage weights were determined in each girth class. The number of culms of a given age class and in each girth class was multiplied by the corresponding mean aboveground biomass value, and the computed biomass of all girth classes was summed to derive the stand biomass.

Biomass of herbs, shrubs and tree seedlings was detemiined separately by harvesting the aboveground biomass during October-November 1992, when most plant categories were at peak biomass. In each replicate site, twenty five m x m quadrats were laid for biomass estimation. The biomass of each plant category was further separated into the main stem, branches and leaves, before oven drying them at 80°C to constant weight. Biomass estimation of saplings and mature trees of miscellaneous species was based on regression equations already derived elsewhere in the Western Ghat region (Rai,l985), for each species between biomass measurements and diameter2 x height (d^2h).

Annual biomass increment of herbs, shrubs, seedlings and saplings was estimated based on sequential measurement of biomass. In the case of teak and miscellaneous trees difference in the aboveground biomass values of 1992 and 1993 represented the annual increment in aboveground biomass. Whereas in the case of bamboo, annual increment in aboveground biomass was the summation of the difference recorded in biomass values of 1992 and 1993 and the biomass produced in the form of new culms in 1993

3.4 Estimation of litter production

Ten 1 m x m litter traps with sides 20 cm high were laid out at each of the three locations on a given site in each plantation. The litter collected at monthly interval (except during rainy season when fortnightly collection was made) from February 1992 to January 1993 was categorized into leaf and non-leaf litter, and further separated into teak, bamboo and miscellaneous plants. Dry weight of litter produced was based on constant weight attained after drying the samples at 80°C.

3.5 Estimation of net productivity

The annual litter production was added to the to annual biomass increment to obtain net primary productivity. No data on herbivory was collected

3.6. Soil and plant chemical analysis

Soil sampling from three replicate plots of each site of each plantation was done in November 1992 at depths 0-10 cm, 10-20 cm and 20-30cm. Ten random samples were collected from each replicate plots and a composite sample was prepared for each depth The air dried soil was ground, passed through a 2-mm sieve and stored in plastic containers Sand, silt and clay contents in air dried 2-mm soil samples were estimated by preparing soil suspension with a dispersant (sodium carbonate + sodium hydroxide) and measuring the density of suspension at stipulated timings using a standardized hydrometer.

The pH of soil was determined electrochemically in a soil-water suspension (1:2.5, by weight) using a glass electrode. Chemical analyses were done following standard procedures (Jackson, 1968; Allen *et al.*,1974; Association of Official Analytical Chemists, 1980). Total nitrogen was determined by the micro-Kjeldahl method, by digestion of soil with sulphuric acid and Kjeldahl-distillation of the ammonium sulphate formed. Exchangeable calcium was extracted with M ammonium acetate solution (pH 7) and estimated by EDTA titration Exchangeable potassium was extracted with sodium acetate extractant (Morgan's reagent) and estimated flame-photometrically.

The weight of each element in the soil was calculated using bulk density estimates (the quotient of dry weight of soil to the total volume it occupies in the field) from the air-dry mass of a known field volume The soil was removed as a disturbed sample and the excavated hole was filled with a measured volume of sand (British Standards Institution, 1967)

For the elemental analysis of vegetation, the samples of teak, bamboo were analyzed separately;the herbs, shrubs and miscellaneous tree species were combined into a composite sample. However, in each case, leaves, branches and main stems (bole in case of teak and culm in case of bamboo) were analyzed separately. Litter samples were also separated into leaf and non-leaf parts, and leaf litter was further categorized as bamboos, teak and miscellaneous species.

Oven-dried plant and litter samples were ground and passed through a 0.5 mm sieve and analyzed following standard procedures (Allen *et al.*, 1974). Thus nitrogen was determined from Kjeldahl digestion. After wet digestion with triple acid, calcium was estimated titrimetrically, while potassium by flame-photometric method

Based on the biomass values obtained for the plant categories at each sampling site. the quantity of various elements in the biomass were estimated. In the same way, based on the annual litter production by the plant categories, the amount of various nutrients returned through them was computed.

3.7 Nutrient Cycling

In the present study, only the cycling of elements between the soil and ground vegetation is considered. The fractional annual turnover of each element was calculated by dividing the weight that left the compartment by the weight held in the compartment and expressed as a percentage (Reiners and Reiners, 1970). Thus for the vegetation, the weight of a given element lost through litterfall was divided by the weight of that element held in the vegetation Similarly, for the soil, the weight of an element taken up by the species/vegetation was divided by the weight of that element held in the soil. To compare the rates at which elements were incorporated into the vegetation, the enrichment ratio was calculated for each element as the quotient of its weight in the aboveground vegetation of a stand divided by its increase in the aboveground living biomass plus litterfall (Woodwell *et al.*, 1975).

3.8 Statistical analysis

Statistical differences between three sites (the bamboo rich area, Site type A; moderately bamboo rich area, Site type B; bamboo poor area, Site type C) for each of the parameters studied were examined through an analysis of variance (ANOVA). If the ANOVA value was found significant ($P \leq 0.05$- 0.001) the parameter mean values were compared using Fisher's least significant difference (LSD) test. The correlation coefficients were computed to measure the mutual relation between teak and bamboo for any given parameter in a given type of site studied.

4. RESULTS

4.1 Floristic composition

The Density, basal area and species diversity index of various plant categories in three site types of teak plantations of different ages are given in Table 1. While shrubs, seedlings, sapling and mature trees of miscellaneous species showed generally higher values for all three parameters in site type C, herbs had more density and basal cover in site type A and species diversity in site type B. Though the density of teak did not show any significant

Table Density, basal area and species diversity index values of diffcrcnt categories of plants in three site types[a] in teak plantations of different ages in Kariem-muriem, Nilambur, Kerala. India.

Plant categories	Density		Basal area		Species diversity	
	Age of the plantation (yr)		Age of the plantation (yr)		Age of the plantation (yr)	
	20	15	20	15	20	15
Herbs						
Site type A	876400	108600	4.10	7.88	0.0788	0.0635
Site type B	786000	84000	2.92	5.99	0.1351	0.0747
Site type C	548400	742000	2.43	4.68	0.1144	0.0702
Shrub						
Site type A	5200	12400	0.13	0.07	0.5367	0.3820
Site type B	3440	-----	0.18	---	0.6271	-----
Site type C	18320	3320	0.95	0.28	0.4024	0.3168
Miscellaneous trees						
<u>Tree seedling</u>						
Site type A-	120	80	0.03	0.04	0.6931	0.6931
Site type B	320	600	0.09	0.20	0.3487	0.1890
Site type C	920	1200	0.21	0.31	0.6692	0.1846

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Table 1,(cont'd . Density, basal area and species diversity index values of different categories of plants in three site types[a] in teak plantations of different ages in Kariem-muriem, Nilambur, Kerala, India.

Plant categories and site types	Density (individuals ha^{-1})		Basal area ($m^2 ha^{-1}$)		Species diversity index (H)	
	Age of the lantation (yr)		Age of the plantation (yr)		Age of the plantation (yr)	
	20	15	20	15	20	15
Miscellaneous trees						
Tree saplings						
Site type A	40	-	0.13	-	0.6931	—
Site type B	L20	120	0.30	0.39	0.2688	0.3500
Site type C	L60	180	0.53	0.54	0.2253	0.2454
Mature trees						
Site type A	22	28	0.33	0.45	0.1830	0.2400
Site type B	36	26	1.53	0.37	0.1290	0.1620
Sitetype C	50	52	3.14	1.29	0.1070	0.1010

Site type A- bamboo rich area: Site type B- moderately bamboo rich area and Site type C- bamboo poor area.

Table 2. Density and basal area of bamboo and teak and percentage frequency and size of bamboo clumps in three site types[a] in teak plantations of different ages in Kariem-muriem, Nilambur, Kerala, India.

Plant categories and parameters	Age of the plantation yr) 20 Site type			15 Site type		
	A	B	C	A	B	C
Bamboo						
Density (Number of clumps ha^{-1})	80 (2.9:	37 (1.7)	12 (1.7)	120 (2.9)	80 (2.9)	22 (1.7)
Percentage frequency	100.0 (0)	91.6 (8.3)	45.8 (8.3)	100.0 (0)	100.0 (0)	70.8 (4.2)
Number of culms ha^{-l}	1876.7 (57.9)	1520.0 (58.7)	300.0 (14.5)	2968.3 (16.4)	1425.0 (48.6)	208.3 (8.3)
Basal area (m^2 ha^{-1})	12.7 (P.22	8.34 (0.86)	2.38 (0.45)	21.17 (3.12)	9.02 (1.02)	0.69 (0.08)
Teak						
Density individuals ha^{-l})	216.7 33.4)	250.0 (0)	300.0 (28.9)	233.3 (60.2)	216.7 (16.7)	333.3 (33.3)
Basal area (m^2 ha^{-l})	12.17 (2.54	17.96 (1.19	23.64 (1.37)	5.97 (1.55	10.34 (1.34)	17.92 (5.61)

Site type A- bamboo rich area; Site type B- moderately bamboo rich area and Site type C- bamboo poor area.

difference among three site type ($P>0.05$) its basal area was significantly highcr ($P<0.05$) in site C than in site type B and A. In the case of bamboo. higher values for density and basal area were recorded in site type A followed by site types B and C. Similarly, number of bamboo culms recorded was also more in site type A followed by B and C. But, no significant difference ($P>0.05$) was observed between site type A and B for percentage frequency values (Table 2).

4.2. Biomass and productivity

Simple linear equations developed between d^2h and biomass of different components of bamboo (culm, branches, foliage and total above-ground plant body) of different ages are given in Table 3. There was a significant correlation between the d^2h values and the dry weight values of different components of bamboo (r=0.769- 0.9653, df=23 ;t-value =4.348- 13.323). The predicted and initial estimates of each component were also strongly correlated (r=0.565-0,969, df=23 Similarly, d^2h value of teak tree was also strongly correlated with dry weights of its different components (Table 4). Strong correlation was found between 'the values of actual dry weight and predicted dry weight of each plant component of teak Total above-ground biomass estimated in 20- and 15-year old teak plantations was 157.3±19.6 and 141.721 8 t ha^{-1} in site type A, 184.3±15.7 and 112.121 .5 t ha^{-1} in site type B and 192.0±10. and 164.9±27.8 t ha^{-1} in site type C. No significant difference was noted in the values of total above-ground biomass in three sites of each plantation ($P>0.05$). In each site type of a given plantation, generally, the contribution of teak to the total above-ground biomass was higher (58.4 and 25.7% in site type A of 20- and 15-year old plantations, 64.6 and 56.5% in site B and 84.3 and 92.7% in site type C). However, contribution of bamboo to the total above-ground biomass was more in site type A (39.8 and 71.9 % in 20- and 15-year old plantations) followed by site type B (30.2% and 40.9%) and site type C (5.7 and

Table 3. The predicted equations for compartmental dry weights of culms of *Bambusa arundinacea* of different ages.

Component (kg)	Culm age (yr)	Simple linear equations[a]	r-value	t-value (df= 22)
culm[b]	1	$9.599 + 111.303\ d^2H$	0.9071	7.768 ***
	2	$9.457 + 77.815\ d^2H$	0.9329	9.338 ***
	3	$10.170 + 97.031\ d^2H$	0.9255	8.619 ***
	>3	$8.298 + 77.672\ d^2H$	0.9279	8.974 ***
Branch	1	$4.310 + 17.690\ d^2H$	0.9237	8.657 ***
	2	$4.530 + 33.510\ d^2H$	0.9284	9.008 ***
	3	$4.099 + 66.236\ d^2H$	0.9312	9.212 ***
	>3	$4.068 + 36.608\ d^2H$	0.9012	7.499 ***
Leaf	1	$1.578 + 5.787\ d^2H$	0.9201	8.4688 ***
	2	$33.876\ d^2H -0.6154$	0.9315	9.235 ***
	3	$2.102 + 5.601\ d^2H$	0.7698	4.348 ***
	>3	$2.302 + 6.545\ d^2H$	0.9358	9.568 ***
Total	1	$15.487 + 134.779\ d^2H$	0.9212	8.5340 ***
	2	$13.371 + 145.202\ d^2H$	0.9653	13.3230 ***
	3	$16.372 + 148.869\ d^2H$	0.9290	9.0500 ***
	>3	$14.668 + 120.826\ d^2H$	0.9242	8.7240 ***

[a], d=Diameter at breast height (in mtr); H= Height of the culm (in mtr)
[b], Culm without branches and leaves. *** ,P 0.001.

Table 4. The predicted equations for compartmental dry weights of *Tectona grandis* of 15-20 year age.

Component (kg)	Simple linear equations"	r-value	t-Value (df=22)
Bole	$0.942 + 512.69\ d^2H$	0.999	611.59 ***
Branch	$0.156 + 144.89\ d^2H$	0.977	21.97 ***
Leaf	74.0 d2H - 2.72	0.994	43.97 ***
Total	$0.26 + 730.55\ d^2H$	0.999	124.26 ***

, d= Diameter at breast height (in mtr);
H= Height of the bole (in mtr). ***, P < 0.001

3.0%). Comparison of the above-ground biomass of teak and bamboo was made for the three site types of each plantation. While significantly higher value for teak biomass was recorded in site type C than in site type A ($P<0.05$) bamboo showed higher value in site type A than in B and C (P<0.00I).

Correlation coefficients were computed to measure the mutual relation between above-ground biomass of bamboo and that of teak. In the case of site type A, biomass of bamboo and teak were negatively correlated ($r = -0.7207$, $n=9$, $P<0.05$) while in site types B and C, no significant correlation was found (site type B; $r= -0.6009$, site C; $r = -0.469$: $n = 9$, $P>0.05$).

Annual litter production recorded in 20- and 15-year plantations was 8.0±0.5 and 9.9±0.9 t ha^{-1} yr^{1} in site type A, 10.0±0.4 and 9.5±0.5 t ha^{-1} yr-1 in site type B and 7.9±0.7 and 6.0±0.2 t ha^{-1} yr^{-1} in site type C. Significantly higher litter production ($P< 0.05-0.01$) was recorded for bamboo in site type A (4.2±0.5 and 6.7±0.7 t ha^{-1} yr^{-1}) than in site types B (3.5±0.7 and 4.620.4 t ha^{-1} yr^{-1}) and C (0.63±0.2 and 0.23±0.01 t ha^{-1} yr^{-I}). On the other hand, for teak significantly higher litter production ($P<0.05-0.01$) was recorded in site type C (6.0±0.9 and 4.5±0.3 t ha^{-1} yr^{-1}) than in site types B (4.9±0.5 and 3.6±0.2 t ha^{-1} yr^{-1}) and A (2.220. and 1.7±0. t ha-1 yr^{-1}). No significant difference in litter production for total vegetation was noticed among the three site types ($P>0.05$).

The annual rate of biomass production of the total vegetation in 20- and 15-year old teak plantations was 23.0±0.9 and 21.3±1.1 t ha^{-1} yr^{-1} in site A, 23.1±0.5 and 16.53±1.2 t ha^{-1} yr^{1} in site B and 10.8±0.9 and 13.4±1.2 t ha^{-1} yr^{1} in site C, with significantly higher values in site type A than in site type B ($P<0.05-0.001$).Similarly, the net primary production of the total vegetation (27.9±0.8 and 30.8±1.7 t ha^{-1} yr^{1} in site A, 23.6±0.3 and

25.0±1.4 ha^{-1} yr^{-1} in site B and 22.0: 2 and 22.3±0.7 ha^{-1} yr. in site C) w a s also significantly higher in site type A than in site type C. In the case of bamboo also,in 20- and 5- yr old plantations, the annual rate of biomass production (1 5.9±0.3 and 13.3±0.3 t ha^{-1} yr^{-1} in site A. 4.5±0.5 and 5.9±0.2 t ha^{-1} yr^{-1} in site B and 720.08 and 0.6±0.06 t ha-1 yr-1 in site C) and the net primary productivity (18.320.8 and 19.0±0.9 t ha^{-1} yr^{-1} in site A, 1 8±0.5 and 9.0±0.5 t ha^{-1} yr^{-1} in site B and 6.3±0.4 and 0.9±0.02 t ha^{-1} yr^{-1} in site C) were significantly higher in site type A than in other site types (P<0.05-0.001 However,teak had higher values for both annual rate of biomass production (6.2±0.8 and 7.1±1.2 t ha^{-1} yr^{-1} in site A, 8.1±0.7 and 9.7±1.4 t ha^{-1} yr^{-1} in site B and 8.2±0.8 and 11.6±1.2 t ha^{-1} yr^{I} in site C) and net primary productivity (8.3±1.5 and 10.5±1.7 t ha^{-1} yr^{-1} in site A, 10;3+0.4 arid 14.7±1.5 t ha^{-1} yr^{-1} in site B and 14.1±0.8 and 19.720.7 t ha^{-1} yr^{I} in site C) in site type C than in site type A (P<0.05-0.01

4.3. Nutrient cycling

Nutrient concentrations generally ranked leaves as the highest and main branches, the lowest; branches, leaf litter and non-leaf litter, intermediate (Table 5). The exception was calcium the concentration of which was higher in the branches and bole in teak and other plants. In the case of bamboo no significant difference between leaves and leaf litter for calcium or nitrogen concentration was recorded (P>0.05).

Quantity of elements in various compartments of living above-ground biomass, rate of release of elements through litter fall, rate of accumulation and rate of uptake of elements in teak, bamboo and composite mixture of other plants (herbs, shrubs, seedlings, saplings and mature trees of miscellaneous tree species) as well as pooled vegetation in each plantation site have been calculated as described in the methodology. Since the values of these parameters

Table 5. Element concentrations (% dry weight) in different plant components in teak, bamboo, and other plants in 15-20 year old teak plantations in Kariem-muriern, Nilambur, Kerala, India. Values in parentheses are SE.

Elements	Main branches	Branches	Leaves	Leaf litter	Non-leaf litter
Bamboo					
Nitrogen	**0.50 (0.01)**	**0.56 (0.02)**	**0.77 (0.04)**	**0.86 (0.06)**	**0.51 (0.02)**
Potassium	**0.18 (0.01)**	**0.19 (0.02)**	**0.32 (0.03)**	**0.16 (0.04)**	**0.20 (0.03)**
Calcium	**0.28 (0.02)**	**0.32 (0.04)**	**0.48 (0.04)**	**0.50 (0.04)**	**0.30 (0.05)**
Teak					
Nitrogen	**0.26 (0.04)**	**0.32 (0.02)**	**0.86 (0.09)**	**0.69 (0.08)**	**0.31 (0.02)**
Potassium	**0.10 (0.03**	**0.20 (0.06)**	**0.58 (0.06)**	**0.13 (0.04)**	**0.18 (0.02)**
Calcium	**0.36 (0.05)**	**0.53 (0.09)**	**0.36 (0.07)**	**0.36 (0.06)**	**0.40 (0.09)**
Miscellaneous plants					
Nitrogen	**0.52 (0.06)**	**0.52 (0.08)**	**0.56 (0.04)**	**1.64 (0.20)**	**0.48 0.03)**
Potassium	**0.12 (0.04)**	**0.12 (0.02)**	**0.23 (0.03)**	**0.10**	**0.09 (0.02)**
Calcium	**0.44 (0.01)**	**0.42 (0.03)**	**0.36 (0.01)**	**0.24 (0.01)**	**0.20 (0.03)**

Table 6 The enrichment quotient elements of vegetation in three site types[a] of teak plantations of different ages in Nilambur, Kerala, India. Data are mean± SE. , n=3.

Age of the plantation and site types	Plant cateuories			
	Teak	Bamboo	Others	Total
Nitrogen				
20-yr				
Site type A	54.1±4.6	71.9±2.7	62.9±O.9	68.0±2.1
Site type B	41.8±0.9	74.3±3.6	56.4±2.6	62.9±2.2
Site type C	38.2±3.4	64.3±7.8	56.4±O.6	42.4±2.7
15-yr				
Site type A	60.6±3.1	54.5±2.6	60.1±1.7	56.0±2.9
Site type B	44.9±1.6	51.8±2.6	60.7±O.8	50.0±2.0
Site type C	48.1±2.8	89.8±3.2	59.1±0.6	45.2±O. 6
Potassium				
20-yr				
Site type A	77.5±3 .4	83.8±l.8	73.6±0.9	82.4±1.5
Site type B	68.1±0.8	85.3±2.4	73.7±2.1	80.O±l.7
Site type C	64.5k3.3	77.8±5.5	69.0±0 .5	67.4±14
15-yr				
Site type A	82.0±1.9	70.8±2.2	70.8±O.6	73.2±2.5
Site type B	70.8±l. 4	68.5±2.2	75.7±0.7	169.7±1.9
Site type C	73.2±2.3	94.4±3.3	71.0±0.6	66.7±0.5
Calcium				
20-yr				
Site type A	78.4±3 .3	69.5±2.9	76.5±0.7	72.8±2.4
Site type B	69.3±O.7	72.1±3.8	4.4±2.1	70.6±2.2
Site type C	65.7±3.2	61.9±8.2	75.l±O .4	65.5±1.6
15-yr				
Site type A	82.8±l. 8	51.6±2.8	74.O±1.3	62.5±3.9
Site type B	71.9±1.3	48.9±2.5	76.5±O.6	61.3±2.3
Site type C	74.3±2.2	81.0±3.0	76.8±O. 5	64.1±0.5

[a], Site type **A-** bamboo rich area; Site type B- moderately bamboo rich area and Site type - bamboo poor area.

were essentially the function of changes in biomass, litter production, annual rate of biomass production and net primary productivity pattern respectively, these values have not been given here. However, these values have been used to calculate enrichment quotient of elements and the fractional turnover of elements in vegetation.

Table 6 shows the enrichment quotient of elements of teak, bamboo, miscellaneous species and the total vegetation in different site types. In general, enrichment quotients of potassium and nitrogen were significantly higher in bamboo than in teak. However, teak had higher enrichment ratios for calcium. Comparison of the three site types of each plantation showed that enrichment ratios of elements for teak were significantly higher in site type A followed by site types B and C; whereas, no clear trend was evident for this parameter in case of bamboo and the total vegetation among three site types. While the general trend of enrichment quotients of elements for teak was Ca≥ K>N, these for bamboo and the total vegetation were K>Ca≥ N and K≥Ca>N respectively

The percentage annual turnover of nitrogen and potassium for bamboo and teak generally showed no significant difference ($P>0.05$). But the fractional annual turnover of calcium was significantly higher in bamboo than in teak (Table 7). The general trend of the fractional turnover of elements in teak was N>K≥Ca and that for bamboo and total vegetation were Ca>N>K and N>Ca≥K respectively. Comparison between sites for the fractional annual turnover rates of elements of teak, bamboo and the total vegetation revealed that there was no significant difference between sites for the values or no regular trend in the values of any given plant category.

Soils of site type A were more sandy than those of site types B and C while clay and silt contents were more in site type C followed by site type A (Table 8). Significantly higher

Table 7. The fractional annual turnover of elements in vegetation in three site types[a] of teak plantations of different ages in Karieni-muriem, Nilambur, Kerala, India. Data are mean ± SE., n=3.

Age of the plantation and site types	Plant categories			
	Teak	Bamboo	Others	Total
Nitrogen				
20-yr				
Site type A	6.3±3.4	10.2±1.4	34.6±6.8	8.8±1.4
Site type B	10.2±2.2	9.2±1.7	4.0±0. 2	9.2±O-9
Site type C	9.2±1.4	9.6±2.7	5.1±0.5	8.7±O.8
15-yr				
Site type A	14.1±4.1	9.7±1.1	17.0±3.6	10.2±l.2
Site type B	14.2±2.6	17.1±2.7	22.4±1.7	15.2±0.7
Site type C	7.8±2.1	6.9±2.1.	14.9±2.9	9.2±2.4
Potassium				
20-yr				
Site type A	2.1±1.5	5.0±1.7	10.0±1.*0*	3.9±O.7
Site type B	3.4±0.7	4.50±.8	1.9±O.1	3.7±0.3
Site type C	2.8±0.3	4.7±1.3	2.1±0.2	2.9±0.2
15-yr				
Site type A	4.7±1.4	4.8±0.5	10.3±2.2	4.8±0.6
Site type B	4.7±0.9	7.3±1.5	11.0±0. 9	6.1±0.2
Site type C	2.6±O.7	3.7±O.4	6.1±1.2	2.9±0.6
Ca1cium				
20-yr				
Site type A	2.0±0. 5	11.5±1.6	8.7±O.8	5.1±1.0
Site type B	3.2±0.7	10.4±1.9	1.8±O.1	4.6±0.5
Site type C	2.7±0.3	10.8±3.0	1.5±O.1	2.9±0.2
15-yr				
Site type A	2.1±0.2	24.7±3.5	8.8±l.9	9.5±l.6
Site type B	1.9±O.4	16.7±1.7	10.5±0.8	4.5±0.7
Site type C	4.1±1.1	8.2±O.8	4.5±O.9	2.5±0.3

[a],Site type A- bamboo rich area; Site type B- moderately bamboo rich area and Site type C- bamboo poor area.

Table 8. Soil physical and chemical properties in three site types[a] of teak plantations of different ages in Kariem-muriem, Nilambur, Kerala, India. Data are mean±SE., n=3. Values in parentheses are SE.

Soil properties	Age of the plantation (yr) 20			15		
	Site type			Site type		
	A	B	C	A	B	C
Sand (%)	85.0 (1.3)	64.0 (3.2)	49.0 (2.2)	84.0 (2.4)	60.0 (4.2)	48.0 (1.8)
Silt (%)	8.7 (0.9)	15.0 (1.2)	29.3 (1.5)	9.6 (1.6)	19.8 (2.4)	34.6 (3.2)
Clay (%)	6.3 (1.0)	21.0 (4.4)	21.7 (1.5)	6.4 (0.8)	20.2 (1.7)	17.4 (3.2)
pH	5.03 (0.05)	5.36 (0.08)	5.74 (0.06)	5.05 (0.05)	5.36 (0.02)	5.81 (0.04)
Total nitrogen (%	0.230 (0.006)	0.287 (0.014	0.376 (0.008)	0.234 (0.018)	0.329 0.030)	0.440 (0.043)
'Extractable Potassium (%)	0.029 (0.002)	0.036 (0.003)	0.027 (0.002)	0.031 (0.001)	0.038 (0.003)	0.026 (0.003)
Extractable calcium (%)	0.586 (0.003)	0.112 (0.006)	0.125 (0.003)	0.084 (0.004)	0.097 (0.002)	0.118 (0.005)
Mass (Kg ha-1) Total nitrogen	7387 (138)	9737 (430)	14336 (408)	7650 (78)	11249 (210)	16896 (192)
Extractable Potassium	935 (42)	1245 (94)	1065 (75)	1014 (24)	1300 (42)	998 (17)
Extractable calcium	2811 (99)	3842 (192)	4808 (132)	2747 (64)	3317 (27)	4531

[a], Site type A- bamboo rich area; Site type B- moderately bamboo rich area and Site type C- bamboo poor area

Table 9 The fractional annual turnover of elements of soil in three site types[a] of teak plantations of differ- ent ages in Kariem - muriem, Nilambur, Kerala, India. Data are mean ± SE., n=3.

Age of the plantation and site types	Plant categories			
	Teak	Bamboo	Others	Total
Nitrogen				
20-yr				
Site type A	**0.46±0.03**	**1.75±0.04**	**0.14±0**	**2.47±0.05**
Site type B	**0.60±0.05**	**1.17±0.02**	**0.08±0**	**1.95±0.03**
Site type C	**0.46±0.06**	**0.11±0.01**	**0.09±0**	**0.69±0.03**
15-yr				
Site type A	**0.41±0.07**	**1.63±0.08**	**0.16±0.02**	**2.31±0.1**
Site type B	**0.40±0.01**	**0.72±0.04**	**0.12±0**	**1.301±0.04**
Site type C	**0.36±0.02**	**0.12±0.01**	**0.80±0**	**0.55±0.01**
Potassium				
20-yr				
Site type A	**1.1±0.1**	**4.5±0.3**	**0.1±0**	**5.7±1.4**
Site type B	**1.2±0.2**	**3.0±0.1**	**0.1±0**	**4.3±0.4**
Site type C	**1.6±1.2**	**0.5±0.1**	**0.2±0**	**2.2±0.3**
15-yr				
Site type A	**1.**0±0.**1**	**3.6±0.3**	**0.2±1.0**	**4.b±0.4**
Site type B	**1.0±0.3**	**1.8±0.2**	**0.2±0.5**	**2.9±0.**3
Site type C	**1.7±0.4**	**0.7±0.2**	**0.2±0.7**	**2.6±0.5**
Calcium				
20-yr				
Site type A	**1.3±0.2**	**2.5±02**	**0.1±0**	**4.0±0.2**
Site type B	**1.5±0.1**	**1.6±0.2**	**0.1±0**	**3.1±0.3**
Site type C	**1.3±0.2**	**0.2±0.1**	**0.1±0**	**1.5±0.2**
15-yr				
Site type A	**1.4±0.2**	**2.5±0.3**	**0.2±0**	**4.0±0.4**
Site type B	**1.3±0.1**	**1.4±0.1**	**0.2±0**	**2.9±0.2**
Site type C	**1.4±0.1**	**0.1±0.1**	**0.1±0**	**1.6±0.2**

[a],Site type A- bamboo rich area; Site type B- moderately bamboo rich area and Site type C- bamboo poor area

values for pH, concentration and quantity of nitrogen and calcium in the soil were recorded in site type C than in other two site types. However, both the concentration and mass of potassium in soil were more in site types B and A than in site type C

The fractional annual turnover of elements in soil showed a clear difference among plant categories (Table 9). While the percentage annual turnover of each element was more in site type A than in site type C for bamboo and the total vegetation, in general, no clear trend was observed for teak. Comparison of the fractional annual turnover of elements in soil showed that while the values for each element for bamboo were higher in site type A, teak had higher values in site type C. The trend of fractional annual turnover rate of elements in soil with respect to teak was $Ca \geq K > N$, and that for bamboo and total vegetation was $K > Ca > N$ and $K \geq Ca > N$ respectively

5. DISCUSSSION

Three site types namely bamboo rich area (site type A), moderately bamboo rich area (site type B) and bamboo poor area (site type C) were recognized based on the distribution pattern of bamboo in teak plantations in the Kariem-muriem Reserve of the Nilambur Forest Division, Kerala. These three site types are also different from each other with respect to the vegetation structure, soil quality, above-ground biomass production and nutrient cycling pattern. A negative correlation between the biomass of bamboo and teak observed in site type A may indicate that the bamboo suppresses the growth of teak by competing with the latter for soil nutrients and space. Poor performance of shrubs, tree seedlings and saplings in terms of biomass production in site type A may also be attributed to the dominance of bamboo in that site. In a given teak plantation, though the site type A is poor in teak biomass production than site type C, there is no significant difference between these two sites for biomass production by the vegetation as a whole. This is due to the fact that in site type A low biomass production by teak is compensated by the high biomass production by bamboo. Thus, the colonized bamboo in site type A makes the site as productive as site type C.

The role of a particular species in the nutrient cycling in a given ecosystem will be evident when the enrichment quotients, the fractional turnover rates of elements in the vegetation and soil are studied to compare these parameters among different species in the system. For example, in the present study, it has been observed that the enrichment quotient values of potassium and nitrogen are higher for bamboo than those for teak. Similarly, in bamboo while the percentage annual turnover rate of potassium is lower than those of other elements studied, the fractional turnover rate of potassium in soil with respect to bamboo was more than those for other elements. These two observations are important in terms of understanding the role of bamboo in the accumulation and release pattern of elements such as nitrogen and potassium. As far as nitrogen is concerned, though bamboo stores more nitrogen in its biomass, much higher turnover rate of this element as compared to that of potassium in bamboo can be seen. This is due to much higher concentration of this element compared to potassium in the leaves and leaf litter (see Fig.2). But, potassium being a labile element is more readily lost than divalent cations through run-off and percolation of water in disturbed ecosystems (Allen, 1964; Lloyd, 1971 Therefore, the rapid accumulation of this element in the biomass is significant in view of the losses in disturbed areas of tropical forest ecosystems. During the ecosystem recovery phases one or more species play an important role in conserving nutrients especially easily leachable elements such as potassium (Bartholomew *et.al.*, l953; Greenland and Kowel, 1960; Swamy and Ramakrishnan, 1987; Chandrashekara and Ramakrishnan, 1994). The role of bamboo species in conserving nutrients, especially potassium, during secondary succession following slash and bum agriculture in north-east India has also been reported (Toky and Ramakrishnan, 1982; Rao and Ramakrishnan. 1989). At this juncture, an attempt may be made to ascertain the possible role played by *Bambusa arundinacea* in conservation of potassium in teak plantations studied. The soil of site type A is characterized by having more potassium than that in the soil of site types B and C. It may also be noted here that the soils of site type A are prone to temporary waterlogging and the loss of nutrients may also be expected due to run-off. Better performance of bamboo under that condition which appears unsuitable for teak, and the capacity of bamboo in accumulating potassium in larger amount as compared with other nutrients suggest that bamboo makes the site not only productive but also helps in conserving easily leachable element,i.e., potassium. Less accumulation of calcium in bamboo biomass and higher fractional annual turnover rate of calcium especially in site type A may indicate faster cycling of calcium in this species and its adaptability to calcium poor soils.

From the nutrient conservation and cycling point of view, teak is not a suitable species for site type A. This is because teak has got the capacity to store calcium in its biomass as observed in this study and thus leading to calcium deficiency in the soil of site type A which is already a calcium poor one. Inability of teak as compared to bamboo to conserve potassium conservation may lead to loss of potassium from the site due to absence of vegetation that can accumulate it at faster rate. Whereas in site type C, which is rich in calcium than site type A, the capacity of teak with more enrichment ratio, low release pattern and faster assimilation rate for calcium makes it suitable for the locality. Thus it can be concluded even from the nutrient cycling point of view that bamboo is the suitable species for site type A and teak is the ideal one for site types B and C. It may be worth mentioning here that Kallarackal *et.al.*(1992) have also observed in case of teak some relation between the water blister problem and the proximity of trees to the water course.

6. MANAGEMENT IMPLICATIONS

Observations made based on differential performance of bamboo and teak in the areas studied, ecological requirements of these two species and their role in biomass production and nutrient cycling have many implications in management of teak plantations especially of site quality II and III. Since even in a given landscape bamboo and teak perform differentailly, managing these two species demands different approaches on the basis of the following findings.

1. Based in this study, teak plantation having bamboo growth can be classified into three site types:

   Site type A: Plots having 3 or more clumps per 400 m^2 and each clump with more than 20 culms or are easily invaded by bamboo,

   Site type B: Plots having 1-3 clumps per 400 m^2 and each clump with 10-19 culms.

   Site type C : Plots having 0-3 clumps per 400 m^2 and if clumps present each with less than 9 culms.

2. Teak does not perform well in terms of biomass production and nutrient stability in areas like site type A of the plantation.

3. Even from the nutrient conservation and cycling point of view, teak is not suitable species for Site type A. This is because the Site type A is rich in potassium and poor in calcium (Table 8). Since teak has the capacity to store calcium deficiency in the soil of Site types A which is already calcium poor. At the same time, inability of teak as compared to bamboo to conserve potassium may lead to loss of potassium from the areas like Site type A due to absence of Vegetation that can accumulate it at rate.

4. Therefore attempts to cultivate teak in areas like Site type A are not advisable.

5. In areas likc Site types B and C which are rich in calcium than in Site type A, the capacity of teak with more enrichment ratio, low release pattern and faster assimilation rate for calicum makes teak suitable for the locality.

6. In teak plantations, bamboo should be preferred to introduce in areas like Site type A which are suitable to bamboo than in Site types B and C where bamboo performs either at moderate or poor level in terms of biomass production.

7. In many tropical forest ecosystems, conserving potassium seems to be crucial, as it is a labile element. Management of such key elements of the ecosystem after pertubation or conversion of natural ecosystems into plantation systems is crucial for the stability of the ecosystem. The present study showed that this function is remarkably achieved by ***Bambusa arundinacea*** in teak plantations of Kerala. Thus attempts to retain or introduce bamboo in teak plantations in areas like Site type A can also help in conservation of nutrients as well as make such land as productive as Site types B and C.

8. Therefore, inter-planting of bamboo in teak plantations especially in areas like Site types B and C may not give good yield as compared to patch-planting alone in areas like Site A. Even from the point of view of silvicultural practices and management of teak and bamboo, the patch-planting has several advantages over inter-planting of bamboo in teak plantations.

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