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The dynamics of biomass and nutrients in bamboo (*Bambusa bambos*) plantations

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Abstract—Bamboo is presently one of the dominant species used in India for plantation. The aim of this research was to obtain quantitative data on the biochemical functioning of the bamboo plantation ecosystem and to provide relevant information to foresters. The results presented here concern biomass and nutrient accumulation in an age series of a bamboo plantation. In particular, to obtain information on ecosystem dynamics, an age series of 1 to 10 years was studied because it is possible that these stands will reveal the assimilation characteristics of different ages and different stages of development in a single plantation.

The biomass production in an age series of *Bambusa bambos* plantation were estimated and compared with its inter species and between genera of natural and plantation stands. There was linear increase of the total biomass of all compartments with the age of the plantation up to six years and then it decreased. In the above ground biomass, the relative percentage contributions were: culms (81%), branches (14%) and leaves (1%). The below ground rhizome contribution was 4%. The total biomass increased from 2.3 t/ha (1 year) to 298 t/ha (6 year) and decreased to 16 t/ha (10 year). The percentage of nutrient distribution in different biomass components varied; the order of major element concentrations was K > N > Mg > Ca > P in leaves. The maximum amount of all nutrients per hectare occurred in the culms, followed by branches, rhizomes and leaves. The present results make it possible to evaluate with sufficient accuracy nutrient losses at crop harvest. These results could be introduced in management models.

Key words: Bamboo plantation; age series; biomass nutrient content; nutrient distribution; nutrient retained.

1. INTRODUCTION

Bamboo, which are giant, woody, tree-like grasses have a long history as an exceptionally versatile and widely used resource. India possibly has the world's richest resources of bamboo with some 130 species occurring over an area of 10.05 million hectares [30]. The diverse bamboo plantations in the natural habitat are dwin-

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dling, due to over-exploitation, shifting cultivation practices and extensive forest fires. Sustained availability can be ensured only by intensive bamboo cultivation for industrial purpose. One promising species for such cultivation is *Bambusa bambos* (L.) Voss., which is planted for long-fibred pulpwood production [28].

The lack of information of nutrient requirements and effects of bamboo silviculture on the environment spursed us to investigate this field. Worldwide research on nutrient cycles has been carried out at one particular stage of stand development, generally on the mature stage [9, 34]. More relevant information in the field of nutrient dynamics according to plantation stand development needs to be obtained.

This work is part of a general investigation, the aim of which is to determine the ecological basis for stand management and to identify the effects of bamboo plantations on the environment and particularly on soils. The total loss of nutrients from the ecosystem by biomass harvesting and by deep drainage will be evaluated and the potential of the soil to supply these elements will be investigated to prevent soil nutrient depletion and to ensure the perenniality of the production.

This particular part of the study will be focused on the effect of plantation age on biomass production, nutrient uptake and distribution.

2. MATERIALS AND METHODS

2.1. Practical organisation of the project

2.1.1. Nursery management practices and transplanting. Since bamboo seeds possess a short period of viability (a few days to 1 month), seedlings from tissue culture were employed for raising bamboo plantations. A nursery area of 10 × 5 m was prepared in the field and filled with a mixture of soil and sand (3 : 1). The seedlings were picked out from the polythene bags when about 7 cm in height. About 25–30 seedlings were planted in 1 m^2 of raised nursery bed. Watering was done 2–3 times a day and care was taken to avoid over saturation. Nursery beds were provided with a thatch to protect the seedlings from direct sunlight.

The seedlings in the nursery were uprooted carefully and transplanted to the field. The seedlings were planted at 6 × 6 m spacing with 250 seedlings per ha. The transplanted seedlings were watered every 2 h regularly in the morning and evening. Weeding was done as and when required. After 1 year, the plantation was adequately irrigated at 15-day intervals. Care was taken to avoid waterlogging. The plantation was protected against damage by rodents, and grazing and browsing animals.

2.1.2. Annual recruitment of culms. The number of new culms produced annually assesses the productivity of bamboo. At a given site the production of new culms mostly depends on the culms of the previous year, the degree of congestion and the clump age. In the trial plantation at Kallipatty, Tamil Nadu State, India culm emergence took place the year following planting. Seedlings of *Bambusa bambos* produced only five culms per clump in the first year after planting. The average number of culms gradually increased in the subsequent years. Culms emerging in the first year were short (1.4 m) in length and small in diameter (2.3 cm at breast height). Culms produced in subsequent years were distinctly taller and thicker.

2.1.3. Ecological situation. The 10-year plantation of *Bambusa bambos* studied was located at Kallipatty, Tamil Nadu, which lies between 11°28′ to 12° E latitude and 76°9′ to 77°47′ N longitude. Its altitude is 540 m above mean sea level. This area soil was laterite, red to brown in colour and sandy loam in texture [35]. The soil moisture content was determined by drying 10 g fresh soil in a hot-air oven at 150°C for 24 h. The pH (7.4–7.8) was observed on an electric digital PH-meter in a 1.5 (w : v) soil–water suspension. For N, P and K, the samples were air dried and sieved (0.2 mm). Total N was estimated by the indophenol blue method described by Allen [1]. The molybdenum blue method of Jackson [16] was followed to determine the available soil P. Potassium was extracted from the soil in an ammonium acetate solution (pH = 7) and was measured with a digital flame photometer (Systronics 121, India). To obtain the total soil nutrient concentrations per hectare, the percentage nutrient content was divided by 100 and the result multiplied by 2 million. One hectare usually contains 2×106 kg of soil [10]. The total soil concentrations of N, P, K, Ca and Mg were 3800, 360, 3600, 1600 and 1800 kg per ha, respectively. Mean temperature and rainfall for the site are 31°C and 600 mm, respectively.

2.1.4. Methodology to evaluate biomass. A special method was progressively adopted to accurately evaluate the biomass and mineral content of forest stands [3, 22, 23].

For the present study, the biomass estimation method can be summarized as follows. In order to estimate the total biomass, in relation to organic productivity, 15 culms were randomly selected from each age group. For reasons of economy, the rhizome was excavated from only 3 in each age group After felling, the total height of each culm, diameter at breast height (DBH), basal area and number of nodes were measured and subdivided into leaves, branches, culm and rhizome. Fresh weight of the components was estimated in the field and the sub-samples from each component were brought to the laboratory in plastic bags. The sub-samples were then oven dried at 103 ± 2°C at constant weight. From the oven-dry weight of the samples, the total standing biomass of each age group was calculated by multiplying the total number of the bamboos of different ages with the average dry weight of the sample.

2.1.5. Nutrient analysis. The bamboo was reduced to sawdust by means of an electrical saw. The sawdust was sieved initially with 65 meshes per cm^2 and later with 200 meshes per cm^2. The materials retained during the second sieving was called 'average wood' and was used for the analysis (the wood used for the analysis was dry). Nitrogen and phosphorous were estimated as described by Armstrong *et al.* (1976) using the Technician Autoanalyser II (Gedko International, UK). The sample was digested in a Kjeldathern digestion system KT 408 (Bonn) at 400°C for 3 h. A 1 g sample was digested in digestion tubes with 2.5 g potassium sulphate and 5 ml H_2SO_4. After digestion and cooling, the digested sample was made up to 100 ml with distilled water and used for analysis of N and P. The nutrients K, Ca and Mg were analysed using an atomic absorption spectrophotometer (Perkin-Elmer 5000, USA) after wet digestion of a 1-g sample with a triple acid mixture (10 ml conc. HNO_3, 4 ml HC 104 and 1 ml conc. HCl). The digested samples were filtered through Whatman No. 42 filter paper and made up to 100 ml with distilled water and this solution was stored and used for analysis [15]. All analysis was performed on the average of three replicates.

3. RESULTS

3.1. Biomass production

It is seen in Table 1 that there was a linear increase in the biomass of all compartments with the age of the plantation up to six years. The culm height increased from 1.4 m to 28.5 m in six years concomitant with the expansion in diameter from 2.3 to 8.3 cm. The total biomass also increased from 2.3 (year 1) to 298 t/ha (year 6). In leaves, biomass increased from 0.166 in the year 1 to 4.0 t/ha in the year 6 which was 24.2 times higher. The branch biomass increased from 0.5 to 39 t/ha in the 6th year, a factor of 80.9. The total above ground biomass (culm, branch, leaves) increased from 1.3 t/ha to 286 t/ha, a factor of 211.3 times. However, the below ground biomass (rhizome) increased from 0.9 t/ha to 11.2 t/ha, which was 11 times higher. In all components, a decrease in biomass accumulation was noticed after the sixth year.

3.2. Nutrient concentration in different components

In Tables 2–5, the average nutrient concentration of four components of bamboo for all six age groups is given. The highest concentration of different nutrients in the various biomass components was generally observed in the order of leaf, branch, culm and rhizome. The proportions of nutrient elements were in the order K > N > Mg > Ca > P except for leaf in which the nutrient elements were found in the order N > K > Mg > Ca > P.

3.3. Distribution of nutrient elements in different components

The distribution of elements in the leaf, branch, culm and rhizome are calculated. The leaf contained 33–36% N, 3–4% P, 31–35% K, 10–16% Ca and 15–17% Mg. The branches contained 31–37% N, 3–4% P, 35–37% K, 10–15% Ca and 11–18% Mg. The higher concentrations were observed in the culm, which

Table 1.
Production of biomass in *Bambusa bamboo* plantation (t/ha)

Age	Culm dia-meter (cm)	Culm height (cm)	Basal area (cm)	No. of culm	No. of codes	Biomass (t/ha)			Total above ground biomass	Rhizome biomass	Grand total biomass
						Leaf	Branch	Culm			
1	2.3	1.4	3.1	1250	7	0.166	0.493	0.698	1.356	0.938	2.294
2	3.3	3.2	4.0	2250	16	0.668	1.897	6.795	9.360	3.150	12.510
3	4.3	9.6	5.0	3000	37	1.122	17.11	29.25	47.487	4.980	52.467
4	4.8	21.8	6.1	3500	86	1.862	27.16	92.75	121.772	6.055	127.827
5	6.3	27.2	8.3	4000	98	3.544	33.94	187.23	224.708	9.600	234.308
6	8.3	28.5	101.1	4250	103	4.021	39.89	242.73	286.637	11.220	297.857
7	5.4	20.5	6.0	3250	81	1.898	21.10	116.95	139.954	8.245	148.199
8	4.1	16.0	5.4	2750	66	1.380	15.66	68.82	85.856	5.390	91.246
9	2.8	8.5	3.6	1500	44	0.477	6.455	20.79	27.732	2.040	29.772
10	2.5	7.4	3.0	900	37	0.246	2.853	11.43	14.259	1.143	15.672

Results are the average of three independent observations. Since there was little difference between observations, average values are given.

Table 2.
Nutrient concentration in the leaves

Nutrients Mg/g-1	1	2	3	4	5	6	7	8	9	10
N	7.9	8.8	9.0	9.3	9.7	10.5	9.2	8.5	7.7	7.3
P	0.8	0.8	0.9	0.9	1.0	1.0	1.0	0.9	0.9	0.9
K	7.6	8.2	8.7	9.0	9.5	1.0	9.0	8.0	7.5	6.9
Ca	2.3	2.9	3.3	3.8	4.4	5.1	5.0	4.5	4.3	4.0
Mg	3.4	3.7	4.3	4.9	5.2	5.4	5.2	4.9	4.5	4.5

Results are the average of three independent observations. Since there was little difference between observations, average values are given.

Table 3.
Nutrient concentration in the branch

Nutrients Mg/g-1	1	2	3	4	5	6	7	8	9	10
N	6.5	6.7	7.0	7.9	8.3	8.9	8.5	8.0	7.6	7.0
P	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8
K	6.7	7.3	7.8	84	8.9	10.0	9.5	8.8	8.4	7.9
Ca	2.0	2.3	2.9	3.1	3.8	4.3	4.0	3.5	3.3	3.0
Mg	3.0	3.2	3.8	4.0	4.6	4.8	4.5	4.0	3.8	3.5

Results are the average of three independent observations. Since there was little difference between observations, average values are given.

Table 4.
Nutrient concentration in the culm

Nutrients Mg/g-1	1	2	3	4	5	6	7	8	9	10
N	6.0	6.4	6.7	7.4	7.8	8.2	8.0	7.5	7.3	7.0
P	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7
K	6.4	6.9	7.4	7.9	8.2	8.9	8.5	8.0	7.8	7.5
Ca	1.8	2.3	3.0	3.6	3.9	4.1	4.0	3.7	3.5	3.0
Mg	2.9	3.3	4.1	4.3	4.4	4.6	4.3	4.0	4.0	3.5

Results are the average of three independent observations. Since there was little difference between observations, average values are given.

contained 30–34% N, 3–4% P, 33–36% K, 10–15% Ca and 17–19% Mg in the aerial shoots of 1–10 year aged-plantation *Bambusa bambos*.

3.4. Nutrient retention

The average annual nutrient retention was obtained by multiplying the productivity of biomass components with their respective nutrient concentration (Fig. 1 [illegible] was observed that, on a unit area basis, the maximum amount of all nutrients [illegible]

Table 5.
Nutrient concentration in the rhizome

Nutrients Mg/g-1	1	2	3	4	5	6	7	8	9	10
N	5.7	6.0	6.3	6.9	7.3	7.7	7.2	6.8	6.3	6.0
P	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.6
K	6.0	6.4	6.9	7.3	7.9	8.4	8.0	7.5	7.2	6.8
Ca	1.6	2.0	2.9	3.4	3.6	3.9	3.5	3.0	2.5	2.3
Mg	2.5	2.7	3.1	3.5	3.9	4.3	4.0	3.8	3.3	3.0

Results are the average of three independent observations. Since there was little difference between observations, average values are given.

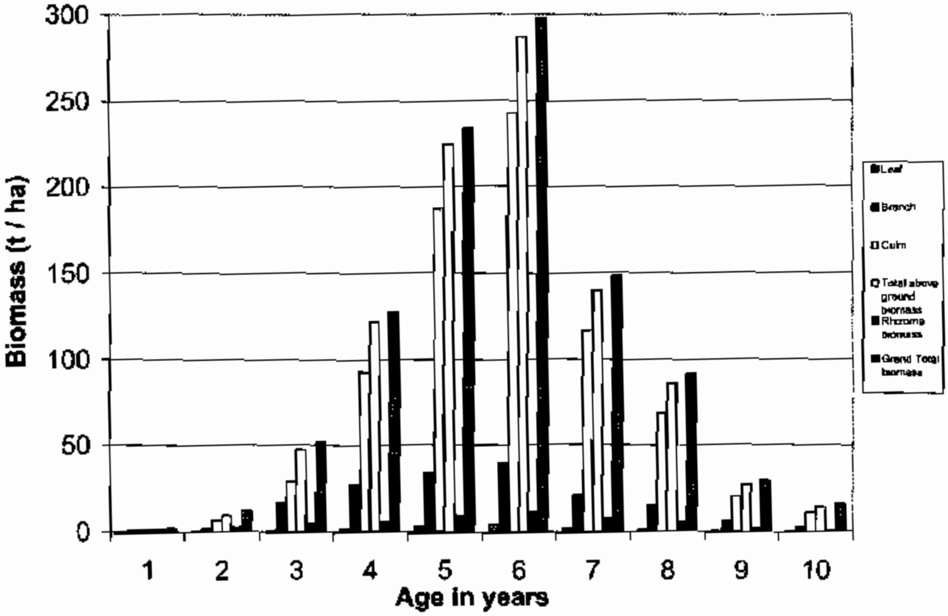

Figure 1.

found in culm followed by branches, rhizome and leaves. Therefore the maximum drain of all nutrients occurred through culm harvest and, among the nutrients, the maximum drain occurred in potassium followed by nitrogen, magnesium, calcium and phosphorus.

4. DISCUSSION

4.1. Biomass production

The biomass (dry matter) of each plantation increased with age as expected. This increment was more prominent in the culm than the other parts of the bamboo. It

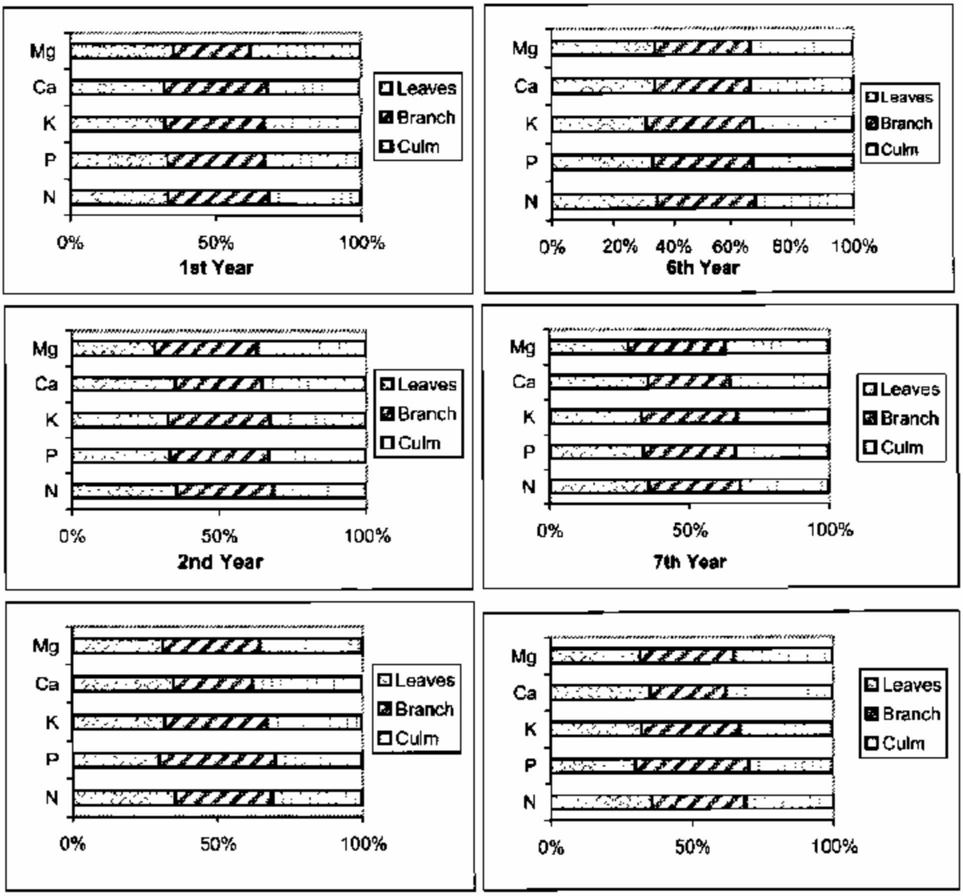

Figure 2.

was observed that the above-ground biomass increased progressively and amounted to 286 t/ha (year 6) and then decreased to 16 t/ha (year 10). Compared with the measured biomass the annual yield of bamboo per ha of the 3 to 4 years old plantation was found to be 7 t/ha for *Bambusa vulgaris* and 1 t/ha for *Gigntochloa aspera* [5]. The above-ground biomass of the plantation was 85% higher. The above-ground biomass of the *Gigantochloa scortechnii* from Malaysia was 72 t/ha in a natural stand and 36 t/ha in a 3 year old plantation [19]. Compared with the biomass of other fast growing tree species — 8 t/ha in the 4 year old *Eucalyptus globulus* [6], 47 t/ha in 5 year old *Leucaena leucocephala* [20] and 87 t/ha in 6 year old *Pinus caribea* [17], the present biomass estimates were 7–30% higher.

4.2. Nutrient dynamics

The nutrients retained in the average annual production were obtained by multiplying the increase in biomass components by their respective nutrient concentration. The nutrient contents of the standing crop differ substantially between various for-

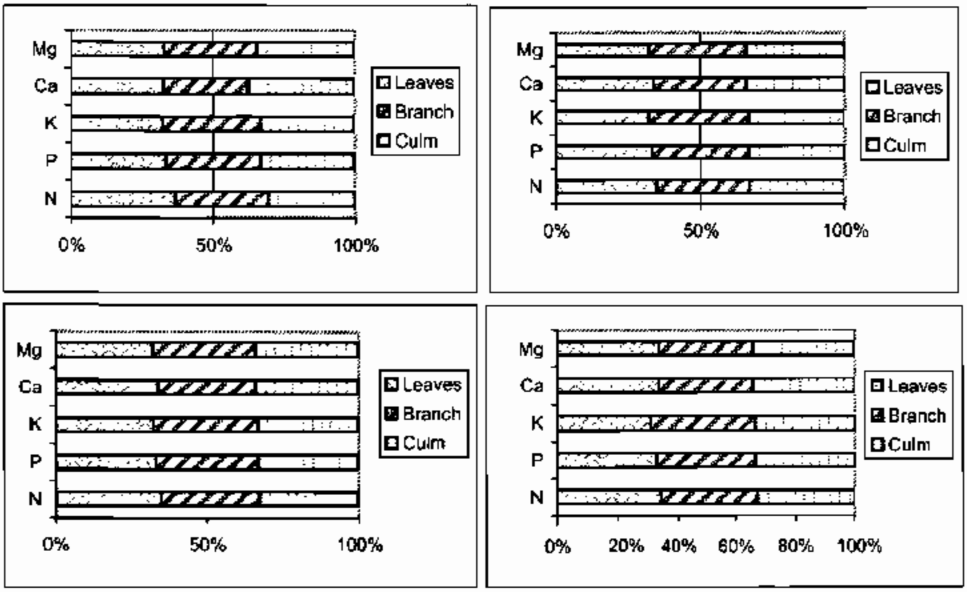

Figure 2. (Continued).

est types according to the degree of uptake and crop biomass, which in turn depend on the age and site quality even within the same species. The increase in nutrient contents of the standing crop with stand age observed in this study has a direct relationship of the biomass of a forest stand [27]. As such, the nutrient accumulated in various tree components varied considerably.

The concentration of nutrients in the aerial shoots and rhizome increased with age. The nutrients elements in leaf were in the order of N > K > Mg > Ca > P, while in branch, culm and rhizome the order was K > N > Mg > Ca > P. These are in general agreement with results for *Dendrocalamus hamiltonii* [33] and *Bambusa balcooa, Dendrocalamus strictus* and *Thyrostachys olivery* [32]. In *Bambusa khasiana* the order was K > N > Mg > Ca > P [25].

Among the cation concentrations, that of potassium was the highest. In this context, bamboo plays an important role in the conservation of potassium because of its capacity for rapid uptake and accumulation. Of the total accumulation of nutrients over 6 years, potassium alone contributed about 51%. The weight of elements increased linearly with biomass [32]. Thus in bamboo plantations, the element potassium is predominant over N, Ca, Mg and P, which is analogous to the effect of slash and burn agriculture on plant nutrients in central Amazonia [4], in a Costa Rican wet forest site [7] in South America, and in *Dendrocalamus strictus* [33] in India. However, the total accumulation of potassium in 6-year-old *Bambusa bambos* in the present study was 5–10% higher than reported by previous workers.

Nitrogen in leaf was found proportionately higher in the present study. Higher allocation of nitrogen to the leaf component may be related to photosynthetic

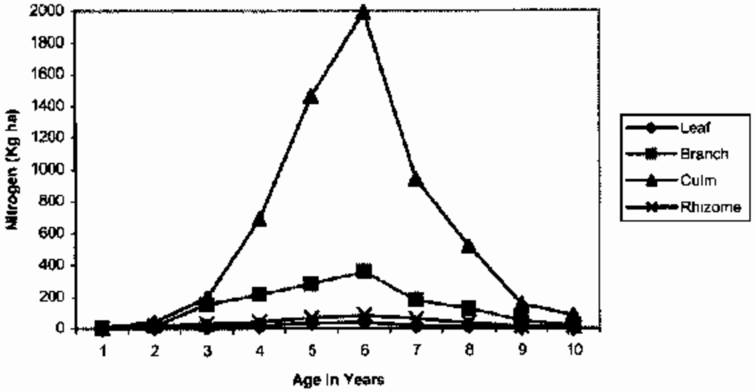

Figure 3.

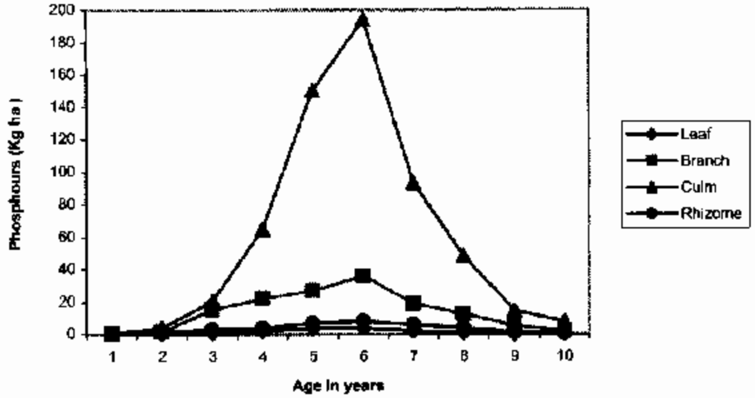

Figure 4.

efficiency, since leaf nitrogen is positively related to photosynthetic rate [8, 18, 31] Natr, 1975; Rao and Ramakrishnan, 1988. In *Dendrocalamus hamiltonii* [33], potassium replaced to leaf nitrogen followed by branches and culms. Annual uptake of calcium and magnesium was higher in comparison with other fast growing tree species [9, 34], Hingston *et al.*, 1988; Negi and Sharma, 1984.

The percentage allocation of nutrients in different compartments of aerial parts of the stand was calculated on a hectare basis and compared. These was a close relation in percentage allocation of dry matter to different compartments of the bamboo which was related to the age of the stand. In a young stand of *Bambusa bambos* of one year old 30% and 7% of dry matter was in the culm and in leaves respectively. Distribution of N, P, K, Ca and Mg was between 4 to 34% in the culm and 4 to 36% in leaves, indicating more allocation of nutrients to the latter. In a six year old stands dry matter and nutrients were more towards the bole than the leaves. With increase in stand age, shift in the nutrient allocation was more towards the bole which reveals more dry matter production in the bole than others [17, Ovington, 1957].

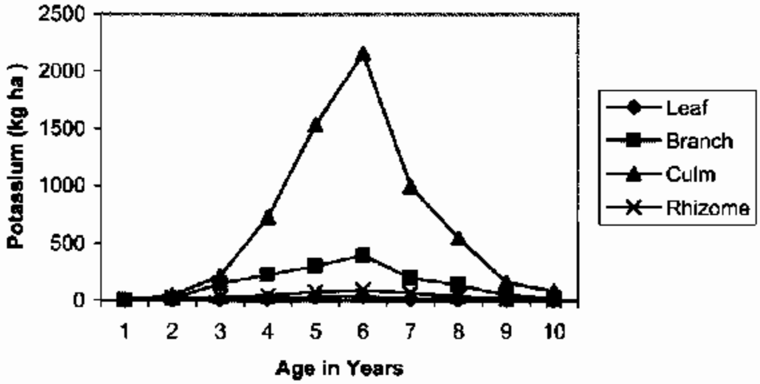

Figure 5.

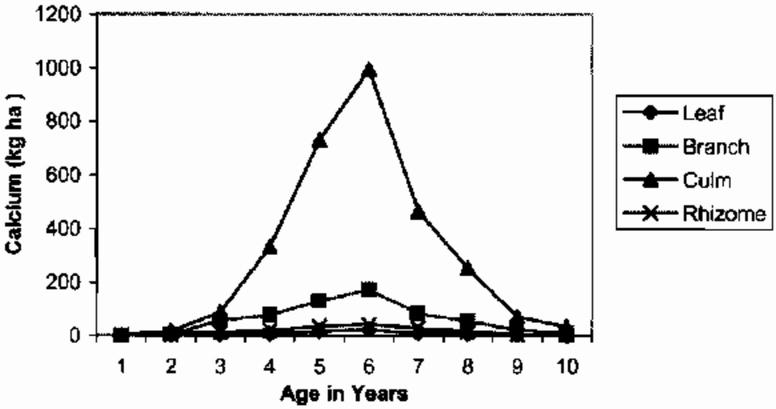

Figure 6.

On unit area basis, the maximum amount of all nutrients was found on culm followed by branches, rhizome and leaves. Therefore the nutrient drain is highest for K followed by N, Mg, Ca and P as in *Dendrocalamus hamiltonii* [33], whereas in *Dendrocalamus hamiltonii, Bambusa tulda, Neohouzeua dulloa* and *Bambusa khasiana* the maximum retention was in the order of K > N > Ca > P [25]. Since the annual nutrient content is usually followed by biomass expansion (average annual production), it increases linearly during the period of rapid growth and diminishes at maturity [21]. The same holds true for *Bambusa Bambos* plantations, where the average annual production is maximum at 6 years of age and similarly the annual accumulation of nutrients also attains a peak a value. These results are in general agreement with earlier observations (Walls and Jorgenson, 1975; Negi and Sharma, 1984).

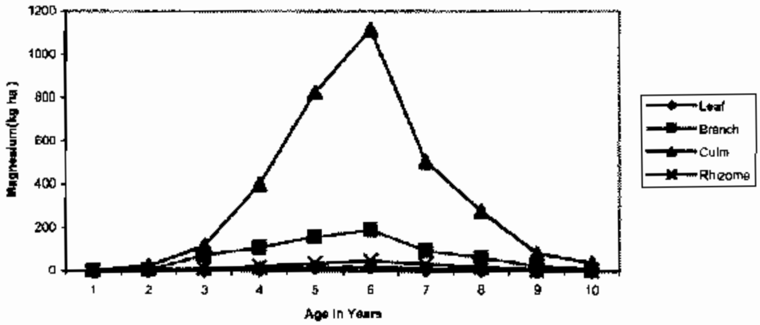

Figure 7.

5. CONCLUSION

An age series of bamboo stands is a useful tool to obtain pertinent information on ecosystem functioning. The plantations selected for this study provide relevant information for accumulation of biomass and nutrients by bamboo stands. The biomass accumulation of plantation bamboo is found to be higher than its counterparts in the natural habitats. This conclusion which needs to be confirmed by other studies. Intensification of forest harvest will inevitably lead to soil impoverishment. The present results obtained on an age sequence of stands make it possible to evaluate nutrient losses during harvest with reasonable accuracy. Several scenarios could be drawn using various rotation lengths and harvesting intensities. These results could be introduced in management models. The input-output budgets for the whole rotation will provide useful information, especially concerning the most accurate quantity of fertilizers both for the sustainability of the production and the conservation of the major parameters of the environment.

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