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Nutrient accumulation, distribution and use efficiency in different bamboo plant species in north-eastern hills region of India

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ABSTRACT

Nutrient accumulation, distribution and use efficiency in 30 bamboo plant species were studied in a 14 years old bamboosetum at ICAR Research Complex for NEH Region, Arunachal Pradesh Centre. Per cent concentration of N, P, Ca, Mn and Z n in different component of biomass had similar pattern in all the species. It was in the order of leaves > branches > stems and the concentration of K, Mg and Fe was in leaves > stems > branches. The N: P: K ratios of above ground biomass varied in different bamboo plant species (76–706 : 1 : 66–930). They showed that P was most limiting nutrient. Bamboo plant species had inherently different response to low P. Recycling of the nutrients through litters showed variability in the range of 2.7–40.9, 0.6–31.4, 1.5–21.1, 3.0–35.4, 1.0–35.4, 2.0–26.3, 0.5–8.0, 1.2–15.0 and 5.0–39.3% of the annual uptake of N, P, K, Ca, Mg, Cu, Fe, Mn and Zn respectively, in different bamboo species. The pattern of nutrient-use efficiency was also different in 30 bamboo plant species.

Key Words: Bamboo species, Cycling, Nutrient accumulation, Nutrient-use efficiency

The bamboos are tall woody tree like grasses which are exceptionally versatile and have been widely used as a renewable resource for various industrial and domestic purposes. A total of 80% of the world's bamboo-growing areas are located in South and South East Asia with India's share ranking second after china only (Sharma 1980, Mauria and Arora 1988). Half of the India's bamboo production originates from north-eastern hills region. Although most bamboo is extracted from natural forests, it is also grown in plantations and agroforestry systems (Tewari *et al.* 1994, Chandrashekara 1996, Kumar 1997, Divakara *et al*. 2001, Singh 2002).

Nutrients acquisition and use efficiency play important role in sustainability of the bamboo plantation. Site quality and sustainability of production in bamboo plantations of short rotation is always a cause of concern due to high nutrient removal in harvested biomass (Wang *et al.* 1991, Kumar *et al.* 1998). Knowledge of the nutrient status of bamboo plantation becomes important for development of suitable fertilizer management plan. Some isolated efforts have been made for evaluation of nutrient uptake, retention in different parts and its effect on soil properties in grooves of *B. bambos, B. Pallida, D. hamiltonii*, *Neohouzeoua. dulloa*, *B. tulda* and *B. khasiana* (Rao and Ramakrishnan 1989, Shanmughavel and Francis 1997, Kumar *et al.* 2005, Singh and Kochhar 2005). However, information on variation in nutrients stocking, distribution and use efficiency in different bamboo species of the north-eastern hills region of India are scarce. The objective of present study was to examine the variation in concentration, nutrients stocking and use efficiency of different nutrient element in different bamboo plant species.

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MATERIALS AND METHODS

A long-term study during July 1988–2003 was conducted at ICAR Research Complex for NEH Region, Arunachal Pradesh Center, Basar, India (27° 95´N latitude and 94° E longitude at an elevation of 660 m above mean sea level in a bambosetum, having clay loam soil. The experimental site experiences humid subtropical climate, with mean annual rainfall of 2 370 mm, distributed over a period of 149 days. Most of the rainfall occurred during the southwest monsoon (April–October). Mean maximum temperature ranges from 12.7°C (January) to 39°C (July–September) and mean minimum temperature varies from 3.3°C (February) to 28.3°C (August). The natural vegetation comprises of wet evergreen and tropical moist deciduous forests. Area represents an Udic soil moisture regime and hyperthermic soil temperature regime. The soil was clay loam (Entisol), acidic in reaction (*p*H 3.2), high in organic carbon (1.65%), low in available P

(4.1 kg/ ha) and high in available K (473 kg/ ha). The exchangeable Ca and Mg contents were 180 and 92 kg/ ha, respectively. The available Zn, Cu, Fe and Mn content determined by the DTPA method were 2.71, 2.64, 336.6 and 98.1 kg/ha, respectiviely.

The rooted slips of 30 bamboo species namely *Arundinaria hirsuta*, *A. mannii*, *Bambusa bambos, B. balcooa, B. cacharensis, B. multiplex, B. nana, B. nutans, B. pallida* Type I, *B. pallida* Type II, *B. polymorpha*, *B. tulda*, *B. striata*, *B. wamin*, *Chimonobambusa armata*, *C. callosa*, *C. griffithiana*, *Dendrocalamus asper*, *D. giganteus*, *D. hamiltonii*, *D. hookerii*, *D. longispathus*, *D. sahnii*, *D. sikkimensis*, *Phyllostachys assamica*, *P. manni*, *P. pubescens*, *Schizostachyum pergracile*, *S. polymorphum* and *S. helferii* collected from different locations were planted in pits of 60 cm × 60 cm × 60 cm size in the bambosetum during monsoon (July 1988–90). Five rooted slips of each species as one treatment were planted randomly in each block following randomized complete block design and there were two replicate plots for each treatment. The plant spacing was 6 m between plants within row and 6 m between rows to achieve planting density of 278 clumps/ha. Experiment was laid out in a randomized block design with 30 bamboo species collected from different locations of the Himalayan region. Planting of rooted slips of bamboo species was done during monsoon (July, 1988) at 6 m × 6 m distance to achieve planting density of 278 clumps/ha. Planting was done in the pits of 60 cm × 60 cm × 60 cm size.

Biomass was determined by harvesting the matured culms every year. In this study harvesting of the matured culms started six years after planting and continued up to 14 years. At first harvesting all the matured culms (>3 years old) were harvested, thereafter, every year, >3 years old culms were harvested every December, after completion of the new shoot growth. Three clumps of each treatment were selected randomly from each replication for estimation of biomass production. Total numbers of culms harvested per clump were recorded at each harvesting. For biomass estimation two culms were selected randomly from each clump and separated into stem, branch and leaf parts and their respective fresh weight were taken in the field. A sub-sample of each component was oven dried at 70°C to a constant weight to calculate the dry matter of each component. Culm, branch and leaf biomass were determined from their respective dry weight to fresh weight ratio. Summing all the biomass components yielded the above ground total (leaves + branches + culm) dry biomass of each culm. The mean total biomass per culm in each bamboo was further extrapolated to biomass production on per hectare scale based on the number of culms produced. Method of Shanmughavel and Francis (1995) with some modification was followed for collection of litter samples under the canopy of each treatment in 2001–02 (14^{th} year). Two grids measuring 0.5 × 0.5 m^2 were randomly placed on the ground. The accumulated litters within the grid were carefully removed at the end of every month. Fresh weight was estimated in the field and subsamples of each treatment were taken to the laboratory. The subsamples were then oven dried at 70°C till constant weight. The sample oven dry weight was used to calculate total annual litter fall.

At the last harvesting (14 years after planting) the dried subsamples of all components and litters from each species were ground to pass 2 mm sieve and analysed for N, P, K, Ca, Mg, Cu, Zn, Mn and Fe. Nitrogen was estimated following the micro-Kjeldahl method. P, K, Ca, Mg, Cu, Zn, Mn and Fe were estimated after digesting the samples in 6:1 HNO_3 - $HClO_4$ (Johnson and Ulrich 1959). Phosphorus was determined following molybdenum blue colour method (Murphy and Riley 1962) and K by flame photometry (Jackson 1958). Ca, Mg, Cu, Zn, Mn and Fe were determined by atomic absorption spectrophotometer (AOAC 1990). The stand nutrient content (culms) of each bamboo species was obtained by determining concentration of individual nutrients (N, P, K, Ca, Mg, Cu, Zn, Mn and Fe) in various plant parts and multiplying them by dry matter in the leaves, branches and stem and finally summing the contents of individual fraction. Per cent nutrient-use efficiency of major and secondary nutrients was worked out using formula: 100 × (dry biomass of the plant part/ nutrient content). Nutrient cycling was calculated using the formula: 100 × (nutrient in litters / (nutrient in standing biomass + nutrient in litters)). Data were analyzed using standard statistical procedures (SAS 9.2). LSD at 95% confidence level was used to compare the mean values of different bamboo species.

RESULTS AND DISCUSSION

Variation in nutrients concentration

The concentration of nutrients in different biomass fractions of bamboo plant species varied significantly (Tables 1–3). The mean concentration of N, P, Ca, Mn and Zn showed similar pattern, i e leaves > branches > stems. But, the concentration of K, Mg and Fe was in the order of leaves > stems > branches. The concentrations of different nutrients in leaves were much higher than the other organs. Higher allocations of the nutrients in the leaves are reported to be associated with its photosynthetic activity (Field and Mooney 1986, Hirose and Werger 1987a, b). The concentration ratios of N: P: K, which could be an indicator of nutrient limitation were in the 481:1:343, 176.6:1:246.8 and 144.8:1:251.9 for leaves, branch and stem respectively. The N: P: K ratios of whole culms of different bamboo species were in the range of 76 to706:1:66 to 930. These ratios of N:P:K were much higher than the values 15:1:26 and 3:1:8, reported for *P. pubescens* by Li *et al.* (1998) and Bamboo Research Institute of Nanjing Forestry University (1974), respectively; and the ratios of 7:1:8 in the grove of *P. reticulata* (Ueda 1960). A ratio of N: P higher than 15:1 has been reported that the growth in vegetation was limited due to low P availability in the soil (Raaimakers 1994, Verhoeven *et al.* 1996) as found

Table 1 Nutrient content (%) in leaves of bamboo species collected from the 14 years old bambosetum

Species	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
A. hirsuta	1.708	0.003	1.328	0.429	0.317	0.010	0.020	0.060	0.060
A. mannii	1.887	0.002	0.652	1.053	0.874	0.010	0.020	0.030	0.110
B. bambos	1.540	0.005	0.830	0.380	0.320	0.010	0.020	0.050	0.140
B. balcooa	1.260	0.005	1.880	0.430	0.290	0.010	0.010	0.060	0.100
B. cacharensis	1.370	0.001	0.530	0.600	0.230	0.010	0.040	0.021	0.040
B. multiplex	0.250	0.003	1.180	0.750	0.490	0.010	0.020	0.050	0.070
B. nana	1.430	0.002	0.780	0.800	0.450	0.010	0.010	0.050	0.100
B. nutans	1.390	0.003	1.200	0.700	0.480	0.010	0.030	0.110	0.050
B. pallida Type I	1.070	0.003	0.750	0.630	0.480	0.010	0.040	0.160	0.090
B. pallida Type II	1.370	0.001	0.800	0.730	0.190	0.010	0.040	0.180	0.060
B. polymorpha	1.300	0.002	0.850	0.430	0.330	0.010	0.040	0.120	0.060
B. tulda	1.600	0.001	0.950	0.630	0.450	0.010	0.050	0.120	0.050
B. striata	0.170	0.005	1.580	0.380	0.270	0.050	0.010	0.040	0.050
B. wamin	1.690	0.002	0.730	0.730	0.730	0.010	0.009	0.050	0.040
C. armata	1.581	0.005	1.080	0.680	0.420	0.010	0.010	0.100	0.060
C. callosa	1.631	0.005	1.115	0.702	0.434	0.010	0.010	0.094	0.062
C. griffithiana	1.430	0.003	0.700	0.430	0.330	0.010	0.020	0.110	0.040
D. asper	1.220	0.002	0.930	0.330	0.290	0.010	0.010	0.090	0.060
D. giganteus	1.260	0.005	1.100	0.430	0.330	0.010	0.010	0.050	0.060
D. hamiltonii	1.620	0.004	1.030	0.730	0.490	0.010	0.010	0.050	0.060
D. hookerii	1.200	0.001	0.930	0.730	0.480	0.010	0.030	0.070	0.070
D. longispathus	1.340	0.001	0.850	0.703	0.470	0.010	0.030	0.010	0.100
D. sahnii	1.530	0.003	0.680	0.680	0.510	0.010	0.040	0.160	0.060
D. sikkimensis	1.220	0.001	0.600	0.700	0.480	0.010	0.040	0.180	0.050
P. assamica	1.570	0.002	0.700	0.700	0.440	0.010	0.040	0.140	0.060
P. mannii	1.330	0.002	1.280	0.149	0.120	0.010	0.010	0.070	0.050
P. pubescens	1.881	0.004	1.051	0.110	0.100	0.100	0.100	0.070	0.050
S. pergracile	1.400	0.003	0.930	0.430	0.350	0.010	0.020	0.100	0.110
S. polymorphum	1.410	0.003	1.280	0.380	0.330	0.010	0.050	0.060	0.120
S. helferii	1.780	0.006	1.250	0.350	0.270	0.010	0.020	0.050	0.090
LSD (P = 0.05)	0.321	0.002	0.964	0.321	0.006	0.047	0.029	0.019	0.064
Mean	1.381	0.003	0.985	0.564	0.392	0.014	0.027	0.084	0.071
SD* (±)	0.341	0.002	0.243	0.198	0.143	0.021	0.022	0.048	0.022

*SD, Standard deviation

Table 2 Nutrient content (%) in branches of bamboo species collected from the 14 years old bambosetum

Species	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
A. hirsuta	0.560	0.003	0.399	0.699	0.409	0.010	0.010	0.010	0.090
A. mannii	0.412	0.005	0.480	0.150	0.360	0.010	0.010	0.020	0.090
B. bambos	0.290	0.001	0.600	0.450	0.290	0.004	0.010	0.010	0.040
B. balcooa	0.360	0.005	0.600	0.380	0.260	0.010	0.018	0.010	0.020
B. cacharensis	0.390	0.001	0.100	0.450	0.300	0.010	0.010	0.010	0.140
B. multiplex	0.490	0.001	0.380	0.450	0.320	0.010	0.010	0.020	0.040
B. nana	0.380	0.002	0.550	0.530	0.320	0.020	0.010	0.020	0.060
B. nutans	0.250	0.005	0.580	0.430	0.300	0.009	0.018	0.030	0.020
B. pallida Type I	0.600	0.001	0.450	0.380	0.270	0.010	0.010	0.020	0.020
B. pallida Type II	0.290	0.002	0.350	0.330	0.320	0.010	0.010	0.050	0.040
B. polymorpha	0.310	0.001	0.400	0.380	0.320	0.013	0.010	0.050	0.060
B. tulda	0.380	0.001	0.280	0.450	0.320	0.004	0.020	0.050	0.050
B. striata	0.060	0.002	0.730	0.730	0.230	0.010	0.010	0.030	0.050
B. wamin	0.270	0.001	0.150	0.480	0.270	0.010	0.010	0.020	0.050
C. armata	0.460	0.001	0.780	0.530	0.330	0.040	0.010	0.030	0.140

(Contd.)

Table 2 (*Concluded)*

Species	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
C. callosa	0.460	0.001	0.780	0.530	0.330	0.060	0.010	0.030	0.140
C. griffithiana	0.240	0.001	0.280	0.580	0.330	0.020	0.010	0.020	0.020
D. asper	0.250	0.001	0.280	0.550	0.360	0.010	0.008	0.040	0.120
D. giganteus	0.070	0.001	0.850	0.550	0.350	0.004	0.002	0.040	0.040
D. hamiltonii	0.050	0.001	0.480	0.530	0.270	0.020	0.010	0.010	0.060
D. hookerii	0.460	0.001	0.730	0.480	0.240	0.010	0.010	0.030	0.050
D. longispathus	0.200	0.001	0.380	0.393	0.267	0.006	0.007	0.033	0.038
D. sahnii	0.360	0.001	0.550	0.380	0.270	0.010	0.030	0.040	0.060
D. sikkimensis	0.280	0.001	0.580	0.550	0.320	0.005	0.010	0.060	0.040
P. assamica	0.410	0.001	0.880	0.350	0.260	0.009	0.010	0.040	0.050
P. mannii	0.589	0.001	0.529	0.350	0.150	0.010	0.010	0.020	0.070
P. pubescens	1.120	0.020	0.700	0.205	0.154	0.003	0.003	0.005	0.019
S. pergracile	0.050	0.001	0.400	0.380	0.300	0.000	0.010	0.060	0.050
S. polymorphum	0.450	0.003	0.480	0.400	0.300	0.090	0.020	0.010	0.070
S. helferii	0.320	0.001	0.380	0.430	0.330	0.009	0.002	0.001	0.009
LSD (P = 0.05)	0.064	0.002	1.824	0.193	0.257	0.003	0.003	0.002	0.016
Mean	0.360	0.002	0.504	0.449	0.295	0.015	0.011	0.027	0.058
SD (±)	0.236	0.004	0.209	0.113	0.056	0.021	0.006	0.017	0.035

Table 3 Nutrient content (%) in culms of bamboo species collected from the 14 years old bambosetum

Species	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
A. hirsuta	0.670	0.005	1.230	0.100	0.250	0.010	0.040	0.020	0.060
A. mannii	0.700	0.003	0.950	0.250	0.450	0.010	0.030	0.030	0.060
B. bambos	0.410	0.004	0.580	0.150	0.780	0.010	0.050	0.040	0.050
B. balcooa	0.200	0.003	0.130	0.100	0.180	0.010	0.050	0.020	0.050
B. cacharensis	0.170	0.005	0.830	0.700	0.270	0.005	0.030	0.020	0.020
B. multiplex	0.340	0.001	0.180	0.100	0.240	0.010	0.040	0.020	0.040
B. nana	0.220	0.003	0.130	0.150	0.090	0.010	0.024	0.010	0.030
B. nutans	0.200	0.001	0.350	0.200	0.330	0.020	0.060	0.040	0.030
B. pallida Type I	0.310	0.005	0.600	0.050	0.600	0.010	0.004	0.010	0.020
B. pallida Type II	0.350	0.001	0.630	0.100	0.240	0.010	0.010	0.030	0.030
B. polymorpha	0.220	0.003	1.580	0.100	0.540	0.010	0.020	0.010	0.050
B. tulda	0.220	0.002	0.480	0.100	0.270	0.010	0.020	0.030	0.030
B. striata	0.810	0.004	0.330	0.150	0.360	0.103	0.030	0.010	0.040
B. wamin	0.378	0.001	0.133	0.033	0.219	0.007	0.020	0.013	0.027
C. armata	0.220	0.001	0.400	0.150	0.090	0.011	0.010	0.010	0.060
C. callosa	0.220	0.001	0.400	0.150	0.090	0.002	0.010	0.010	0.060
C. griffithiana	0.200	0.001	0.280	0.150	0.240	0.010	0.050	0.040	0.050
D. asper	0.410	0.001	0.680	0.100	0.450	0.010	0.016	0.024	0.030
D. giganteus	0.240	0.001	0.430	0.150	0.570	0.010	0.020	0.030	0.020
D. hamiltonii	0.270	0.003	0.380	0.150	0.270	0.007	0.010	0.020	0.020
D. hookerii	0.360	0.002	0.800	0.050	0.150	0.010	0.010	0.010	0.030
D. longispathus	0.250	0.003	0.500	0.066	0.271	0.007	0.011	0.015	0.017
D. sahnii	0.280	0.002	0.480	0.100	0.270	0.010	0.010	0.020	0.020
D. sikkimensis	0.220	0.002	0.780	0.100	0.210	0.007	0.010	0.010	0.020
P. assamica	0.210	0.001	0.300	0.100	0.540	0.009	0.010	0.030	0.030
P. mannii	0.280	0.001	1.030	0.100	0.450	0.009	0.010	0.020	0.030
P. pubescens	0.350	0.001	0.630	0.007	0.032	0.013	0.013	0.024	0.045
S. pergracile	0.180	0.001	0.180	0.100	0.150	0.001	0.010	0.020	0.040
S. polymorphum	0.210	0.003	0.400	0.100	0.150	0.010	0.010	0.030	0.040
S. helferii	0.270	0.002	0.500	0.100	0.360	0.013	0.020	0.020	0.020
LSD (P = 0.05)	0.193	0.001	0.193	ns	0.032	0.003	0.006	0.029	0.019
Mean	0.312	0.002	0.543	0.132	0.304	0.012	0.022	0.021	0.036
SD (±)	0.132	0.001	0.313	0.040	0.167	0.020	0.010	0.009	0.013

at the the experimental site (4.1 kg/ha) which was extremely acidic soil (*p*H 3.2). Five species of bamboo consisting of *B. arundinacea, B. balcooa, B. cacharensis, B. pallida* Type I and *D. hamiltonii,* exhibited relatively lower ratio. Another five species consisting of, *B. nutan, B. tulda, D. giganteus, D. hookerii* and, *D. sikkimensis,* showed higher N:P:K ratios. Variation in mineral ratio in the biomass of bamboo species is indicative of the variation in adaptive mechanism of different species in low soil nutrient environment.

Variation in nutrient stocking

Total amount and relative proportion of the N, P, K, Ca, Mg, Cu, Fe, Mn and Zn in leaves, branches and stems varied significantly among different bamboo species (Table 4-6). Shanmughavel and Francis (2001, 1997a, b), Kumar *et al.* (2005) and Singh and Kochhar (2005) had also observed similar quantum of nutrient stocking in the above ground biomass of 30 bamboo species. The relative proportions of the nutrients accumulated in different plant parts in 30 bamboo

Table 4 Mean annual stocking (kg/ha) of the nutrients in leaves of different bamboo species estimated in the 14 years old bambosetum

Species	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
A. hirsuta	3.66	0.01	2.85	0.92	0.68	0.02	0.04	0.13	0.13
	(7.2)	(1.7)	(3.2)	(9.9)	(3.6)	(2.9)	(1.5)	(8.4)	(2.9)
A. mannii	3.37	0.01	1.16	1.88	1.56	0.02	0.04	0.05	0.20
	(6.4)	(1.8)	(17)	(9.7)	(4.7)	(2.5)	(1.7)	(2.5)	(4.3)
B. bambos	448.80	1.46	241.89	110.74	93.26	2.91	5.83	14.57	40.80
	(11.1)	(4.1)	(4.4)	(6.6)	(1.4)	(3.3)	(1.4)	(4.1)	(8.5)
B. balcooa	323.19	1.28	482.22	110.30	74.39	2.57	2.57	15.39	25.65
	(16.1)	(4.9)	(27.7)	(10.6)	(4.8)	(3.1)	(0.6)	(8.9)	(6.2)
B. cacharensis	334.13	0.12	129.26	146.33	56.09	2.44	9.76	5.12	9.76
	(46.3)	(1.5)	(8.8)	(10.5)	(9.8)	(19.3)	(16.2)	(12.9)	(11.6)
B. multiplex	16.29	0.20	76.87	48.86	31.92	0.65	1.30	3.26	4.56
	(9.2)	(30.6)	(45.2)	(41.7)	(22.2)	(12.8)	(7.7)	(26.9)	(20.5)
B. nana	141.67	0.20	77.28	79.26	44.58	0.99	0.99	4.95	9.91
	(46.3)	(9.8)	(35.6)	(35.0)	(33.5)	(11.2)	(6.7)	(38.8)	(29.7)
B. nutans	433.87	0.94	374.57	218.50	149.83	3.12	9.36	34.34	15.61
	(38.5)	(22.9)	(22.9)	(22.5)	(11.9)	(4.6)	(4.7)	(20.6)	(13.7)
B. pallida Type I	209.25	0.59	146.67	123.20	93.87	1.96	7.82	31.29	17.60
	(24.2)	(5.8)	(11.0)	(46.9)	(7.4)	(8.9)	(49.8)	(59.6)	(30.5)
B. pallida TypeII	228.98	0.17	133.71	122.01	31.76	1.67	6.69	30.09	10.03
	(44.3)	(14.8)	(21.2)	(52.2)	(13.0)	(16.5)	(44.2)	(52.1)	(27.5)
B. polymorpha	141.32	0.22	92.40	46.75	35.87	1.09	4.35	13.05	6.52
	(49.5)	(11.7)	(9.5)	(35.0)	(10.2)	(14.5)	(27.4)	(57.3)	(17.0)
B. tulda	624.22	0.39	370.63	245.79	175.56	3.90	19.51	46.82	19.51
	(44.0)	(5.7)	(19.3)	(35.0)	(15.9)	(10.9)	(22.5)	(30.3)	(15.3)
B. striata	4.98	0.15	46.28	11.13	7.91	1.47	0.29	1.17	1.47
	(3.3)	(16.3)	(38.2)	(20.4)	(10.3)	(7.4)	(5.0)	(32.3)	(15.2)
B. wamin	28.61	0.03	12.36	12.36	12.36	0.17	0.01	0.85	0.68
	(52.7)	(42.5)	(56.1)	(61.8)	(43.2)	(24.8)	(0.6)	(45.2)	(23.8)
C. armata	21.79	0.07	14.89	9.38	5.79	0.14	0.14	1.38	0.83
	(23.5)	(19.9)	(10.5)	(14.7)	(15.0)	(3.4)	(4.5)	(28.5)	(4.0)
C. callosa	13.98	0.04	9.56	6.02	3.72	0.09	0.09	0.81	0.53
	(25.8)	(21.8)	(11.7)	(16.3)	(16.6)	(6.9)	(5.1)	(29.1)	(4.5)
C. griffithiana	96.22	0.20	47.10	28.93	22.21	0.67	1.35	7.40	2.69
	(51.4)	(48.1)	(27.8)	(21.8)	(16.4)	(11.3)	(6.8)	(32.0)	(12.3)
D. asper	165.92	0.27	126.48	44.88	39.44	1.36	1.36	12.24	8.16
	(35.0)	(40.8)	(20.3)	(26.8)	(10.2)	(14.7)	(10.3)	(37.0)	(20.1)
D. giganteus	699.84	2.78	610.97	238.83	183.29	5.55	5.55	27.77	33.33
	(32.9)	(46.1)	(16.5)	(15.8)	(4.9)	(8.4)	(4.5)	(12.1)	(18.7)
D. hamiltonii	171.83	0.42	109.25	77.43	51.97	1.06	1.06	5.30	6.36
	(35.5)	(10.9)	(18.5)	(25.6)	(13.4)	(10.0)	(7.9)	(18.2)	(18.0)

(Contd.)

Table 4 (*Concluded*)

Species	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
D. hookerii	334.28	0.14	259.07	203.36	133.71	2.79	8.36	19.50	19.50
	(19.8)	(1.9)	(8.1)	(41.0)	(18.8)	(7.0)	(18.5)	(31.8)	(14.4)
D. longispathus	214.59	0.08	136.12	112.60	75.30	1.60	4.86	1.60	16.01
	(46.0)	(2.8)	(21.4)	(49.8)	(21.2)	(19.0)	(31.7)	(8.2)	(43.4)
D. sahnii	368.29	0.72	163.68	163.68	122.76	2.41	9.63	38.51	14.44
	(47.1)	(20.9)	(19.0)	(47.2)	(24.1)	(14.4)	(36.0)	(55.0)	(29.6)
D. sikkimensis	322.69	0.13	158.70	185.15	126.96	2.65	10.58	47.61	13.23
	(27.0)	(1.7)	(5.0)	(28.1)	(13.1)	(8.9)	(21.3)	(49.6)	(13.9)
P. assamica	247.84	0.32	110.50	110.50	69.46	1.58	6.31	22.10	9.47
	(40.7)	(16.8)	(16.8)	(36.9)	(7.6)	(10.5)	(28.1)	(30.8)	(15.7)
P. mannii	4.56	0.01	4.39	0.51	0.41	0.03	0.03	0.24	0.17
	(41.1)	(25)	(18.3)	(15.8)	(4.7)	(15.6)	(14.3)	(37.1)	(19.3)
P. pubescens	17.47	0.04	9.76	1.02	0.93	0.93	0.93	0.65	0.47
	(37.9)	(13.4)	(19.9)	(30.7)	(23.0)	(57.4)	(56.8)	(33.3)	(15.7)
S. pergracile	115.00	0.25	76.39	35.32	28.75	0.82	1.64	8.21	9.04
	(49.6)	(26.9)	(34.1)	(26.9)	(19.3)	(69.9)	(18.7)	(31.6)	(23.5)
S. polymorphum	18.53	0.04	16.82	4.99	4.34	0.13	0.66	0.79	1.58
	(61.4)	(23.6)	(48.8)	(39.1)	(35.0)	(8.7)	(55.0)	(43.7)	(43.7)
S. helferii	92.56	0.31	65.00	18.20	14.04	0.52	1.04	2.60	4.68
	(22.0)	(12.3)	(10.0)	(10.3)	(8.7)	(3.3)	(4.5)	(10.7)	(17.1)
LSD (P = 0.05)	6.29	0.02	4.98	2.62	1.84	0.04	0.15	0.54	0.34

Figures in parentheses are per cent of the total in above ground plant parts

Table 5 Mean annual stocking (kg/ ha) of the nutrients in branches of different bamboo species estimated in the 14 years old bambosetum

Species	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
A. hirsuta	1.20	0.01	0.86	1.50	0.88	0.02	0.02	0.02	0.19
	(2.4)	(1.7)	(1.0)	(16.1)	(4.7)	(2.9)	(0.8)	(1.4)	(4.3)
A. mannii	1.03	0.01	1.20	0.38	0.90	0.03	0.03	0.05	0.23
	(2.0)	(5.8)	(1.8)	(1.9)	(2.7)	(3.4)	(1.2)	(2.3)	(5.0)
B. bambos	213.77	0.74	442.28	331.71	213.77	3.20	7.37	7.37	29.49
	(5.3)	(2.1)	(8.1)	(19.8)	(3.2)	(3.6)	(1.7)	(2.1)	(6.1)
B. balcooa	159.89	2.22	266.48	168.77	115.48	4.44	8.00	4.44	8.88
	(8.0)	(8.4)	(15.3)	(16.2)	(7.4)	(5.3)	(2.0)	(2.6)	(2.1)
B. cacharensis	118.90	0.31	30.49	137.19	91.46	3.05	3.05	3.05	42.68
	(16.5)	(3.7)	(2.1)	(9.9)	(15.9)	(24.1)	(5.1)	(7.7)	(50.8)
B. multiplex	33.60	0.07	26.06	30.86	21.94	0.69	0.69	1.37	2.74
	(19.0)	(10.8)	(15.3)	(26.3)	(15.3)	(13.5)	(4.0)	(11.3)	(12.3)
B. nana	49.54	0.26	71.70	69.09	41.72	2.61	1.30	2.61	7.82
	(16.2)	(12.9)	(33.1)	(30.5)	(31.3)	(29.6)	(8.8)	(20.4)	(23.4)
B. nutans	81.43	1.63	188.91	140.06	97.71	2.80	5.80	9.77	6.51
	(7.2)	(39.8)	(11.6)	(14.4)	(7.8)	(4.2)	(2.9)	(5.9)	(5.7)
B. pallida Type I	70.80	0.12	53.10	44.84	31.86	1.18	1.18	2.36	2.36
	(8.2)	(1.2)	(4.0)	(17.1)	(2.5)	(5.3)	(7.5)	(4.5)	(4.1)
B. pallida Type II	34.49	0.24	41.63	39.25	38.06	1.19	1.19	5.95	4.76
	(6.7)	(21.1)	(6.6)	(16.8)	(15.6)	(11.8)	(7.9)	(10.3)	(13.0)
B. polymorpha	27.26	0.04	35.17	33.41	28.14	1.10	0.88	4.40	5.28
	(9.5)	(2.4)	(3.6)	(25.0)	(8.0)	(14.6)	(5.5)	(19.3)	(13.7)
B. tulda	130.31	0.34	96.02	154.32	109.74	1.50	6.86	17.15	17.15
	(9.2)	(5.0)	(5.0)	(22.0)	(10.)	(4.2)	(7.9)	(11.1)	(13.5)

(Contd.)

Table 5 (*Concluded)*

Species	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
B. striata	1.40	0.05	17.00	17.00	5.36	0.23	0.23	0.70	1.16
	(0.9)	(5.2)	(14.0)	(31.2)	(7.0)	(1.2)	(4.0)	(19.3)	(12.1)
B. wamin	3.18	0.01	1.77	5.66	3.18	0.12	0.12	0.24	0.59
	(5.8)	(7.5)	(8.0)	(28.3)	(11.1)	(17.3)	(9.0)	(12.6)	(20.7)
C. armata	12.65	0.01	21.45	14.58	9.08	1.10	0.28	0.83	3.85
	(13.7)	(4.0)	(15.1)	(22.9)	(23.5)	(27.4)	(9.0)	(17.0)	(18.8)
C. callosa	7.23	0.01	12.25	8.33	5.18	0.94	0.16	0.47	2.20
	(13.3)	(4.0)	(15.0)	(22.6)	(23.1)	(72.7)	(9.0)	(16.9)	(18.7)
C. griffithiana	21.27	0.04	24.82	51.41	29.25	1.77	0.89	1.77	1.77
	(11.4)	(10.5)	(14.6)	(38.8)	(21.6)	(29.9)	(4.5)	(7.7)	(8.1)
D. asper	24.41	0.05	27.34	53.70	35.15	0.98	0.74	3.91	11.72
	(5.2)	(7.3)	(4.4)	(32.0)	(9.1)	(10.6)	(5.6)	(11.8)	(28.9)
D. giganteus	51.84	0.37	629.49	407.31	259.20	3.10	1.48	29.62	29.62
	(2.4)	(6.1)	(17.0)	(27.0)	(7.0)	(4.7)	(1.2)	(12.9)	(16.7)
D. hamiltonii	5.11	0.05	49.06	54.17	27.60	2.04	1.02	1.02	6.13
	(1.0)	(1.3)	(8.3)	(17.9)	(7.1)	(19.2)	(7.6)	(3.5)	(17.4)
D. hookerii	115.33	0.13	183.02	120.34	60.17	2.51	2.51	7.52	12.54
	(6.8)	(1.7)	(5.7)	(24.3)	(8.5)	(6.3)	(5.5)	(12.5)	(9.3)
D. longispathus	27.83	0.07	52.87	54.70	37.14	0.90	0.96	4.53	5.35
	(6.0)	(2.5)	(8.3)	(24.2)	(10.4)	(10.6)	(6.2)	(23.2)	(14.5)
D. sahnii	50.73	0.14	77.51	53.55	38.05	1.41	4.23	5.64	8.46
	(6.5)	(4.1)	(9.0)	(15.4)	(7.5)	(8.4)	(15.8)	(8.0)	(17.3)
D. sikkimensis	51.52	0.09	106.72	101.20	58.88	0.99	1.84	11.04	7.36
	(4.3)	(1.2)	(3.4)	(15.3)	(6.1)	(3.3)	(3.7)	(11.5)	(7.7)
P. assamica	44.81	0.06	96.18	38.25	28.42	1.00	1.09	4.37	5.46
	(7.3)	(2.9)	(14.6)	(12.8)	(3.1)	(6.4)	(4.9)	(6.1)	(9.1)
P. mannii	1.60	0.01	1.44	0.95	0.41	0.03	0.03	0.05	0.19
	(14.4)	(10.7)	(6.0)	(29.5)	(4.6)	(12.4)	(11.4)	(8.4)	(21.3)
P. pubescens	10.40	0.19	6.50	1.91	1.43	0.03	0.03	0.05	0.18
	(22.5)	(67.6)	(13.2)	(57.5)	(35.4)	(1.6)	(1.6)	(2.5)	(5.9)
S. pergracile	4.38	0.04	35.00	33.25	26.25	0.01	0.88	5.25	4.38
	(1.9)	(4.8)	(15.6)	(25.4)	(17.6)	(0.9)	(10.0)	(20.2)	(11.4)
S. polymorphum	5.37	0.04	5.73	4.77	3.58	1.07	0.24	0.12	0.84
	(17.8)	(21.8)	(16.6)	(37.4)	(28.9)	(71.4)	(20.0)	(6.6)	(23.1)
S. helferii	37.12	0.06	44.08	49.88	38.28	1.00	0.21	0.10	1.00
	(8.8)	(2.3)	(6.8)	(28.3)	(23.9)	(6.3)	(0.9)	(0.4)	(3.7)
LSD (P = 0.05)	1.76	0.02	4.62	3.14	2.02	0.04	0.07	0.26	0.33

Figures in parentheses are per cent of the total in above ground plant parts

Table 6 Mean annual stocking (kg /ha) of the nutrients in culms of different bamboo species estimated in the 14 years old bambosetum

Species	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
A. hirsuta	45.94	0.34	84.34	6.86	17.14	0.69	2.74	1.37	4.11
	(90.4)	(96.6)	(95.8)	(73.9)	(91.7)	(94.2)	(97.7)	(90.2)	(92.8)
A. mannii	48.00	0.21	65.14	17.14	30.86	0.69	2.06	2.06	4.11
	(91.6)	(92.4)	(96.5)	(88.4)	(92.6)	(94.1)	(97.1)	(95.2)	(90.6)
B. bambos	3368.44	32.86	4765.11	4232.36	3408.25	82.16	410.7	328.63	410.79
	(83.6)	(93.7)	(87.4)	(73.6)	(95.4)	(93.1)	(96.9)	(93.7)	(85.4)
B. balcooa	1523.81	22.86	990.48	761.91	1371.43	76.19	380.9	152.38	380.95
	(75.9)	(86.7)	(56.9)	(73.2)	(87.8)	(91.6)	(97.3)	(88.5)	(91.7)
B. cacharensis	268.55	7.90	1311.16	1105.80	426.52	7.14	47.39	31.59	31.59
	(37.2)	(94.9)	(89.1)	(79.6)	(74.3)	(56.5)	(78.7)	(79.4)	(37.6)

(Contd.)

Table 6 (*Concluded*)

Species	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
B. multiplex	127.06	0.37	67.27	37.37	89.69	3.74	14.95	7.47	14.95
	(71.8)	(58.6)	(39.5)	(31.9)	(62.5)	(73.6)	(88.2)	(61.7)	(67.2)
B. nana	114.71	1.56	67.79	78.21	46.93	5.21	12.53	5.21	15.64
	(37.5)	(77.3)	(31.3)	(34.5)	(35.2)	(59.2)	(84.5)	(40.8)	(46.9)
B. nutans	611.26	1.53	1 069.71	611.26	1 008.58	61.13	183.38	122.25	91.69
	(54.2)	(37.3)	(65.5)	(63.0)	(80.3)	(91.2)	(92.4)	(73.5)	(80.6)
B. pallida Type I	585.28	9.44	1 132.80	94.40	1 132.80	18.88	6.71	18.88	37.76
	(67.6)	(93.0)	(85.0)	(36.0)	(90.0)	(85.7)	(42.7)	(35.9)	(65.4)
B. pallida TypeII	253.12	0.72	455.62	72.32	173.57	7.23	7.23	21.70	21.70
	(49.0)	(64.1)	(72.2)	(31.0)	(71.3)	(71.6)	(47.9)	(37.6)	(59.5)
B. polymorpha	117.04	1.60	840.56	53.20	287.28	5.32	10.64	5.32	26.60
	(41.0)	(85.9)	(86.8)	(40.0)	(81.8)	(70.9)	(67.0)	(23.4)	(69.3)
B. tulda	665.28	6.05	1 451.52	302.40	816.48	30.24	60.48	90.72	90.72
	(46.9)	(89.2)	(75.7)	(43.0)	(74.1)	(84.8)	(69.6)	(58.6)	(71.2)
B. striata	1 42.16	0.70	57.92	26.33	63.18	18.14	5.27	1.76	7.02
	(95.7)	(78.4)	(47.8)	(48.3)	(82.6)	(91.4)	(90.9)	(48.4)	(72.7)
B. wamin	22.52	0.04	7.90	1.98	13.04	0.40	1.19	0.79	1.58
	(41.4)	(50.0)	(35.9)	(9.9)	(45.6)	(57.9)	(90.4)	(42.2)	(55.5)
C. armata	58.08	0.26	105.60	39.60	23.76	2.78	2.64	2.64	15.84
	(62.7)	(76.1)	(74.4)	(62.3)	(61.5)	(69.2)	(86.5)	(54.5)	(77.2)
C. callosa	33.00	0.15	60.00	22.50	13.50	0.26	1.50	1.50	9.00
	(60.8)	(74.2)	(73.3)	(61.1)	(60.2)	(20.3)	(85.9)	(53.9)	(76.7)
C. griffithiana	69.70	0.17	97.58	52.28	83.64	3.49	17.43	13.94	17.43
	(37.2)	(41.4)	(57.6)	(39.4)	(61.9)	(58.8)	(88.6)	(60.3)	(79.6)
D. asper	282.99	0.35	469.34	69.02	310.59	6.90	11.09	16.90	20.71
	(59.8)	(51.8)	(75.3)	(41.1)	(80.6)	(74.7)	(84.1)	(51.1)	(51.0)
D. giganteus	1 377.46	2.87	2 467.95	860.91	3 271.48	57.39	114.79	172.18	114.79
	(64.7)	(47.7)	(66.5)	(57.1)	(88.1)	(86.9)	(94.2)	(75.0)	(64.6)
D. hamiltonii	307.22	3.41	432.39	170.68	307.22	7.54	11.38	22.76	22.76
	(63.4)	(87.8)	(73.2)	(56.5)	(79.4)	(70.8)	(84.5)	(78.2)	(64.5)
D. hookerii	1 236.86	6.87	2 748.57	171.79	515.36	34.36	34.36	34.36	103.07
	(73.3)	(96.3)	(86.1)	(34.7)	(72.7)	(86.6)	(76.0)	(56.0)	(76.3)
D. longispathus	223.93	2.69	447.86	58.91	243.11	5.94	9.52	13.43	15.55
	(48.0)	(94.7)	(70.3)	(26.0)	(68.4)	(70.4)	(62.1)	(68.6)	(42.1)
D. sahnii	361.68	2.58	620.02	129.17	348.76	12.92	12.92	25.83	25.83
	(46.3)	(74.9)	(72.0)	(37.3)	(68.4)	(77.2)	(48.2)	(36.9)	(53.0)
D. sikkimensis	819.72	7.45	2 906.28	372.60	782.46	26.11	37.26	37.26	74.52
	(68.6)	(97.1)	(91.6)	(56.5)	(80.8)	(87.8)	(75.0)	(38.8)	(78.3)
P. assamica	316.20	1.51	451.71	150.57	813.08	13.12	15.06	45.17	45.17
	(51.9)	(80.2)	(68.6)	(50.3)	(89.2)	(83.6)	(67.0)	(63.0)	(75.1)
P. mannii	4.94	0.02	18.17	1.76	7.94	0.16	0.18	0.35	0.53
	(44.5)	(64.3)	(75.7)	(54.7)	(90.7)	(72.0)	(74.2)	(54.5)	(59.4)
P. pubescens	18.25	0.05	32.85	0.39	1.68	0.66	0.68	1.25	2.32
	(39.6)	(18.9)	(66.9)	(11.7)	(41.6)	(41.0)	(41.5)	(64.2)	(78.4)
S. pergracile	112.50	0.63	112.50	62.50	93.75	0.34	6.25	12.50	25.00
	(48.5)	(68.3)	(50.2)	(47.7)	(63.0)	(29.2)	(71.3)	(48.1)	(65.1)
S. polymorphum	6.27	0.09	11.94	2.99	4.48	0.30	0.30	0.90	1.19
	(20.8)	(54.5)	(34.6)	(23.4)	(36.1)	(19.9)	(25.0)	(49.7)	(33.1)
S. helferii	291.60	2.16	540.00	108.00	388.80	14.16	21.60	21.60	21.60
	(69.2)	(85.4)	(83.2)	(61.3)	(67.3)	(90.3)	(94.5)	(88.9)	(79.2)
LSD (P = 0.05)	22.91	0.24	36.87	11.30	42.37	0.77	3.40	2.36	3.28

Figures in parentheses are per cent of the total in above ground plant parts

Table 7 Annual bioamss production (Mg/ ha) by different bamboo plant species

Species	Leaf	Branch	Culm
A. hirsuta	0.214	0.214	6.857
A. mannii	0.179	0.250	6.857
B. bambos	29.143	73.714	821.571
B. balcooa	25.650	44.414	761.907
B. cacharensis	24.389	30.486	157.971
B. multiplex	6.514	6.857	37.370
B. nana	9.907	13.036	52.143
B. nutans	31.214	32.571	305.630
B. pallida Type I	19.557	11.800	188.800
B. pallida Type II	16.714	11.893	72.321
B. polymorpha	10.871	8.793	53.200
B. tulda	39.014	34.293	302.400
B. striata	2.929	2.329	17.550
B. wamin	1.693	1.179	5.950
C. armata	1.379	2.750	26.400
C. callosa	0.885	1.571	15.00
C. griffithiana	6.729	8.864	34.850
D. asper	13.600	9.764	69.021
D. giganteus	55.543	74.057	573.943
D. hamiltonii	10.607	10.221	113.786
D. hookerii	27.857	25.071	343.571
D. longispathus	16.014	13.914	89.571
D. sahnii	24.071	14.093	129.171
D. sikkimensis	26.451	18.400	372.6002
P. assamica	15.786	10.929	150.571
P. mannii	0.343	0.271	1.764
P. pubescens	0.929	0.929	5.214
S. pergracile	8.214	8.750	62.500
S. polymorphum	1.314	1.193	2.986
S. helferii	5.200	11.600	108.000
LSD (P = 0.05)	0.951	1.822	6.821

Table 8 Nutrient-use efficiency (Mg of biomass/kg nutrient) of bamboo plant species grown in bambosetum species grown in bambosetum

Species	N	P	K	Ca	Mg
A. hirsuta	0.14	20.22	0.08	0.78	0.39
A. mannii	0.14	33.14	0.11	0.38	0.22
B. bambos	0.23	26.37	0.17	0.55	0.14
B. balcooa	0.41	31.56	0.48	0.80	0.53
B. cacharensis	0.29	25.55	0.14	0.15	0.37
B. multiplex	0.29	79.28	0.30	0.43	0.35
B. nana	0.25	37.17	0.35	0.33	0.56
B. nutans	0.33	90.32	0.23	0.38	0.29
B. pallida Type I	0.25	21.71	0.17	0.84	0.17
B. pallida Type II	0.20	89.31	0.16	0.43	0.41
B. polymorpha	0.26	39.17	0.08	0.55	0.21
B. tulda	0.26	55.41	0.20	0.53	0.34
B. striata	0.15	25.34	0.19	0.42	0.30
B. wamin	0.16	110.25	0.40	0.44	0.31
C. armata	0.33	87.23	0.22	0.48	0.79
C. callosa	0.32	87.15	0.21	0.47	0.78
C. griffithiana	0.27	120.10	0.30	0.38	0.37
D. asper	0.20	137.88	0.15	0.55	0.24
D. giganteus	0.33	116.87	0.19	0.47	0.19
D. hamiltonii	0.28	34.60	0.23	0.45	0.35
D. hookerii	0.24	55.53	0.12	0.80	0.56
D. longispathus	0.26	42.07	0.19	0.53	0.34
D. sahnii	0.21	48.50	0.19	0.48	0.33
D. sikkimensis	0.35	54.36	0.13	0.63	0.43
P. assamica	0.29	94.29	0.27	0.59	0.19
P. mannii	0.21	79.00	0.10	0.74	0.27
P. pubescens	0.15	25.25	0.14	2.13	2.27
S. pergracile	0.34	86.37	0.35	0.61	0.53
S. polymorphum	0.18	34.25	0.16	0.43	0.44
T. helferii	0.30	49.33	0.19	0.71	0.28
Mean ± SD	0.25 ±0.07	61.25 ±33.96	0.21 ±0.09	0.58 ±0.33	0.43 ±0.38

species are significantly different due to variation in elemental concentrations and biomass yield. *S. polymorphum* and *B. wamin* had higher proportions of N (52.7 to 61.4%), P (23.6 to 42.5%), K (48.8 to 56.1%), Ca (39.1 to 61.8), Mg (35 to 43.2%), Mn (45.2 to 43.7%) and Zn (23.8 to 43.7%) accumulation in leaves owing to higher partitioning of total biomass towards leaves (Table 7). Similarly, *A. hirsuta*, *A. mannii*, *B. balcooa* and *B. bambos* had highest accumulation of all the nutrients in the culms. Variation in the distribution of nutrient in different plant parts of various bamboo species were also reported (Rao and Ramakrishnan 1989, Singh and Kochhar 2005). Some bamboo species, viz *B. balcooa B. bambos, D. sikkimensis* and *D. giganteus* showed higher accumulation of all the nutrients in culms (Table 6). This can be attributed to production of high biomass by these bamboo plant species (Table 7). Nutrients accumulated in culms of these species are indicative of very high nutrients export potential of these species through harvest of the culms (Shanmughavel and Francis 1997 b, Embaye *et al.* 2005, Kumar *et al.* 2005).

Pattern of accumulation of major and secondary nutrients in the leaves were in the order of N>K>Ca>Mg>P except in *A. mannii* (N>Ca>Mg>K>P), *B. balcooa* (K>N>Ca>Mg>P), *D. sikkimensis* and *B. cacharensis* (N>Ca>K>Mg>P), *B. multiplex* and *B. striata* (K>Ca>Mg>N>P). In branches and stem, no definite trend was noticed in nutrient accumulation. In majority of the bamboo species, K was the dominant cation in both the plant parts. Accumulation of Zn and Mn in the leaves was much higher than the Cu and Fe except in B. striata. In the branches of different bamboo species, accumulation of Zn was relatively more than the Fe, Mn and Cu in most of the species whereas in culms the accumulation of Zn, Fe and Mn was relatively more than Cu. Variability in pattern of nutrient accumulation in different plant parts as

Table 9 Per cent recycling of the nutrients through litters in different bamboo species

Species	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
A. hirsuta	5.80	2.44	1.78	8.84	3.61	5.19	1.40	3.18	6.74
A. mannii	3.75	4.35	1.46	3.00	1.48	2.67	0.93	1.82	5.02
B. bambos	8.58	0.57	2.44	6.12	0.98	6.07	0.91	1.21	6.09
B. balcooa	15.43	0.72	8.38	6.64	4.09	4.26	0.47	2.31	5.87
B. cacharensis	4.34	1.77	5.71	4.10	6.76	19.04	6.90	10.67	12.39
B. multiplex	4.69	7.25	18.10	17.42	11.03	16.34	3.91	6.85	20.99
B. nana	31.60	3.81	16.87	16.26	12.37	26.28	8.68	8.97	27.35
B. nutans	25.31	15.67	11.83	12.90	4.04	5.34	3.31	2.44	12.64
B. pallida Type I	21.22	3.52	5.88	22.00	2.44	7.75	14.15	4.70	23.57
B. pallida Type II	20.45	9.60	9.97	24.77	18.05	18.76	20.77	6.42	24.19
B. polymorpha	24.44	5.58	4.66	13.60	4.02	12.27	3.23	5.68	17.42
B. tulda	22.24	5.57	10.00	11.64	5.19	10.14	2.26	3.27	17.05
B. striata	3.16	8.16	13.98	18.42	8.39	2.02	6.01	10.15	16.23
B. wamin	29.60	11.11	19.69	25.93	12.81	25.27	1.50	15.00	23.18
C. armata	24.41	7.89	6.15	16.54	21.53	7.59	8.96	8.85	10.16
C. callosa	20.57	9.09	5.10	13.80	18.25	11.03	7.41	7.33	8.50
C. griffithiana	34.89	22.22	17.76	26.25	21.86	16.60	4.05	6.66	11.05
D. asper	22.70	30.93	10.24	32.04	9.30	14.60	8.72	5.84	19.20
D. giganteus	18.35	31.36	4.67	16.72	3.84	7.69	3.90	3.25	15.66
D. hamiltonii	18.64	6.04	13.48	20.01	8.08	10.58	8.56	5.71	15.24
D. hookerii	19.71	2.06	3.41	25.66	15.99	10.19	5.63	6.19	13.45
D. longispathus	29.80	2.74	12.93	28.01	16.09	20.68	9.12	9.19	22.96
D. sahnii	27.26	8.24	11.96	25.25	13.58	15.55	6.46	6.58	24.20
D. sikkimensis	22.22	2.54	2.54	17.15	9.10	10.77	2.13	5.32	13.93
P. assamica	2.67	9.18	8.96	24.68	6.29	10.54	3.19	2.02	9.96
P. mannii	32.85	21.05	18.64	17.86	6.11	21.43	14.29	7.14	16.04
P. pubescens	20.35	9.68	9.74	32.52	27.84	8.47	6.29	5.34	13.20
S. pergracile	29.79	11.54	14.15	24.75	19.35	16.31	12.30	5.39	20.39
S. polymorphum	40.89	27.27	21.06	35.44	35.42	12.28	16.20	10.45	39.33
S. helferii	22.36	9.64	8.77	10.25	3.80	7.49	2.14	3.34	14.70
Mean ± SD	20.27	9.72	10.01	18.62	11.06	12.11	6.46	6.04	16.22
	±10.29	±8.62	±5.75	±8.60	±8.37	±6.41	±5.04	±3.15	±7.48

observed in different bamboo species were found in consistent with the published result (Pritchett 1979, Toky and Ramakrishnan 1982, Toky and Ramakrishnan 1983, Rao and Ramakrishnan, 1989, Shanmughavel and Francis 1997a, b, Tewari *et al*. 1994, Li *et al*. 1998).

Nutrient-use efficiency

The nutrient-use efficiency of different bamboo species was expressed as the above ground dry biomass of whole culms produced per unit nutrients stocked therein (Table 8). The nutrients-use efficiency in different bamboo plant species, did not follow a consistent pattern for all the nutrients. This variation in nutrient-use efficiency might be due to variation in the nutrient concentration and biomass production. *B. balcooa* was most efficient bamboo plant species for N. The most efficient species for P, K and Mg were *D. asper, B. balcooa* and *C. armata,* respectively. *D. hookerii* and *B. balcooa* were most efficient species for the Ca. This variation in nutrient-use efficiency can be used to evaluate the nutrient costs of biomass production (Wang et al. 1991). Any bamboo species considered ideal for a target site, should have rapid biomass accumulation, remove few nutrients and adapted to poor sites where growth may be limited by the rate of nutrient availability. Kumar *et al.* (1998) suggested that the nutrient use efficiency and biomass production can be used for selection of bamboo species ideal for short rotation plantations.

Nutrient cycling

Nutrient cycling of N, P, K, Ca, Mg, Cu, Fe, Mn and Zn for different bamboo species were in the range of 2.7 to 40.9, 0.6 to 31.4, 1.5 to 21.1, 3.0 to 35.4, 1.0 to 35.4, 2.0 to 26.3, 0.5 to 8.0, 1.2 to 15.0 and 5.0 to 39.3%, respectively (Table 9). Indicating, the nutrient and species wise variation in the nutrient turnover to the soil through litter fall. Lower cycling of P and K as compared to other major nutrients possibly indicated relatively greater growth limitation due to P and K, because the retention of growth limiting nutrients are typically more in infertile soils. Higher retention of K and P were also reported in natural bamboo forest (Toky and Ramakrishnan 1982, Aerts and de Caluwe 1994, Maily *et al.* 1997, Eckstein *et al.* 1999, Embaye *et al.* 2005). The nutrient cycling in B. bambos were low (8.5% N, 0.5% P, 2.4% K, 6.1% Ca, 0.98% Mg, 6.1% Cu, 0.9% Fe, 1.2% Mn and 6.1% Zn) however, nutrient accumulation in above ground biomass was highest in this species, indicating a wide gap between the nutrient removal and return to the soil.

In planning sustainable short rotation bamboo-based plantation, apart from biomass accumulation, site nutrient removal through biomass harvesting and nutrient-use efficiency must also be taken into account. Bamboo plant species differ inherently with respect to accumulation, acquisition and nutrient-use efficiency under the acid soil condition. The N: P: K of different bamboo species was in the range of 76 to 706:1:66 to 930:12 to 316:11 to 617. The wider N: P: K ratio indicated low P availability in the acidic soil. In different bamboo species, 2.1 to 51.2% of the total nutrients were present in branch and leaves. Hence, nutrient drain from the bamboo plantation site can be minimized by removing only culms and allowing the branches and leaves to decompose at the site to compensate nutrient loss due to harvest.

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REFERENCES

Aerts R and de Caluwe H. 1994. Nitrogen use efficiency of *Carex* species in relation to nitrogen supply. *Ecology* **75**: 2362–72.

Association of Official Agricultural Chemists. 1990. *Official Methods of Analysis*. Washington, DC.

Bamboo Research Institute of Nanjing Forestry University.1974. *Cultivation of Bamboo Groves*, 278pp. Agricultural Press, Beijing.

Chandrashekara U M. 1996. Ecology of *Bambusa arundinacea* (Retz.) Willd. growing in teak plantations of Kerala, India. *Forest Ecology and Management* **87**: 149–62.

Divakara B N, Kumar B M, Balachandran P V and Kamalam N V. 2001. Bamboo hedgerow systems in Kerala, India: Root distribution and competition with trees for phosphorus. *Agroforestry Systems* **51**: 189–200.

Eckstein R L, Karlsson P S and Weih M. 1999. Research review: leaf life span and nutrient resorption as determinants of plant nutrient conservation in temperate-arctic regions. *New Phytology* **143**: 177–89.

Embaye K, Weih M, Ledin S and Christersson L. 2005. Biomass and nutrient distribution in a highland bamboo forest in southwest Ethiopia: implications for management. Forest Ecology Management **204**: 159–69.

Field C and Mooney H A. 1986. The photosynthesis-nitrogen relationship in wild plants. *On the Economy of Plant Form and Function*, pp 25–55. Givnish T J (Ed.). Cambridge University Press, Cambridge.

Hirose T and Werger M J A. 1987a. Nitrogen use efficiency in instantaneous and daily photosynthesis of leaves in the canopy of a *Solidago altissima* stand. *Physiologia Plantarum* **70**: 215–22.

Hirose T and Werger M J A. 1987b. Maximizing daily canopy photosynthesis with respect to the leaf nitrogen allocation pattern in the canopy. *Oecologia* **72**: 520–6.

Jackson M L. 1958. *Soil Chemical Analysis*, 498pp. Prentice Hall, New Jersey.

Johnson C M and Ulrich A. pp 26–78 1959. *Analytical Methods for Use in Plant Analysis, Bulletin* 766, University of California, Agricultural Experiment station, Berkeley.

Kumar B M. 1997. Bambos in the homegardens of Kerala: A shrinking resource base. *Journal of Non-timber Forest Products* **4** (3/4): 156–9.

Kumar B M, George S J, Jamaludheen V and Suresh T K. 1998. Comparison of biomass production, tree allometry and nutrient use efficiency of multipurpose trees grown in wood lot and silvopastoral experiments in Kerala, India. *Forest Ecology and Management* **112**: 145–63.

Kumar M, Rajesh G and Sudheesh K G. 2005. Aboveground biomass production and nutrient uptake of thorny bamboo [*Bambusa bambos* (L.) Voss] in the homegardens of Thrissur, Kerala. *Journal of Tropical Agriculture* **43** (1–2): 51–6.

Li R, Werger M J A, During H J and Zhong Z C. 1998. Carbon and nutrient dynamics in relation to growth rhythm in the giant bamboo *Phyllostachys pubescens*. *Plant and Soil* **201**: 113–23.

Maily D, Christanty L and Kimmins J P. 1997. 'Without bamboo, the land dies': nutrient cycling and biogeochemistry of a Javanese bamboo *talun-kebun* system. *Forest Ecology and Management* **91**: 155–73.

Mauria S and Arora R K. 1988. Genetic resources of bambos— an Indian perspective. *Indian Forestry* **114**: 539–48.

Murphy J and Riley J P. 1962. A modified single solution method for determination of phosphates in natural waters. *Analytica Chimica Acta* **27**: 31–6.

Pritchett W C. 1979. *Properties and Management of Forest Soils*. John Wiley & Sons, London.

Raaimakers D. 1994. Growth of *Tropical Rain Forest Trees as Dependent on Phosphorus Supply*. *Tropenbos series* 11, 97 pp. The Tropenbos Foundation, Wageningen.

Rao K S and Ramakrishnan P S. 1989. Role of bamboos in nutrient conservation during secondary incession following slash and burn agriculture (Jhum) in North East India. *Journal of Applied Ecology* **26**: 625–34.

SAS 9.2 2002-2008. SAS Institute Inc., Cary, NC, USA.

Shanmughavel P and Francis K. 2001. Bioproductivity and nutrient cycling in bamboo and acacia plantation forests. *Bioresource Technology* **80**: 45–8.

Shanmughavel P and Francis K. 1995. Litter production in *Bambusa bambos* plantation. *Bangladesh Journal of Forest Science* **24**: 31–4.

Shanmughavel P and Francis K. 1997. Balance and turnover of nutrients in a bamboo plantation (*Bambusa bambos*) of different ages. *Biology and Fertility of Soils* **25**: 69–74.

Shanmughavel P and Francis K. 1997 b. The dynamics of biomass and nutrients in bamboo (*Bambusa bambos*) plantations. *Journal of Bamboo and Rattan* **1**: 157–70.

Sharma Y M L. 1980. Bambos in the Asia-Pacific region. Bamboo research in Asia. *Proceedings of the Workshop held at Singapore*, May 28–30, International Development Research Centre, Ottawa, Canada.

Singh K A. 2002. Boom of bamboo resources in North-East India. *Resource Management Perspective of Arunachal Agriculture,* 351 pp. Singh KA (Ed.). ICAR Research Complex for NEH Region, Arunachal Pradesh Centre, Basar.

Singh K A and Kochar S. 2005. Effect of clump density/spacing on the productivity and nutrient uptake in *Bambusa pallida* and the changes in soil properties. *Journal of Bamboo and Rattan* **4**: 323–34.

Tewari S K, Kumar N, Katiyar R S, Balasubramanian V R and Misra P N. 1994. Preliminary observations on the comparative performance of three bamboo species on alkali soils of Utter Pradesh. *Bamboo News* **19**: 1–3.

Toky O P and Ramakrishnan P S. 1983. Secondary succession following slash and burn agriculture in north-eastern India. II. Nutrient cycling. *Journal of Ecology* **71**: 747–57.

Toky O P and Ramakrishnan P S. 1982. Role of bamboo (*Dendrocalamus hamiltonii* Nees and Arn.) in conservation of potassium during slash and burn agriculture (Jhum) in northeastern India. *Journal of Tree Science* **1**: 17–26.

Ueda K. 1960. Studies on the physiology of bamboo. *Bulletin of the Kyoto University Forests* **30**: 1–69.

Verhoeven J T A, Koerselman W and Meuleman A F M. 1996. Nitrogen- or phosphorus-limited growth in herbaceous, wet vegetation: relations with atmospheric inputs and management regimes. *Trends in Ecology and Evolution* **11**: 494–97.

Wang D, Bormann F H, Lugo A E and Bowden R D. 1991. Comparison of nutrient-use efficiency and biomass production in five tropical tree texa. *Forest Ecology and Management* **46**: ±1–21.