Aboveground biomass production and nutrient uptake of thorny bamboo [*Bambusa bambos* (L.) Voss] in the homegardens of Thrissur, Kerala

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Abstract

To estimate the aboveground biomass stock and nutrient uptake of *Bambusa bambos*, nine hedgerow-raised (20 year-old) clumps were destructively sampled. Aboveground biomass of bamboo clumps averaged 2417 kg per clump with an average per ha accumulation of 241.7 Mg ha^{-1}. Highest biomass accumulation was observed in the live culms (82%), followed by thorns+foliage (13%); dead culms accounted for only ~5% of the biomass accumulation. Allometric relationships linking clump biomass and culm number with clump diameter were developed. Nutrient export through harvest (NPK) varied among the tissue types with the highest in live culms, followed by leaves+twigs and dead culms. Average N, P and K removals were 9.22, 1.22 and 14.4 kg per clump respectively. Litter accumulation on the forest floor averaged 909 g m^{-2} accounting for 48.15, 3.67 and 42.98 of N, P and K g m^{-2} respectively.

Keywords: Hedgerows, litter accumulation, nutrient export, rural bamboo

Introduction

Bamboos occur extensively in the managed ecosystems of India—both as plantations (Chandrashekara, 1996) and in agroforestry (scattered clumps, hedgerows on farm boundaries etc., Kumar, 1997; Divakara et al., 2001). It has a long history as an exceptionally versatile and widely used resource. Important traditional uses include paper and pulp, fuel, food, feed, house construction, scaffolding, making several articles of everyday use (Sharma, 1987), controlling soil erosion and facilitating on-site nutrient conservation (Christanty et al., 1996). In a rapidly changing world, however, households develop a myriad of livelihood options and in several cases bamboos are considered to be an important livelihood strategy of rural people. Coincidentally, bamboo is being elevated from a raw material known as the "*poor man's timber*", to the status of the "*timber of the 21st century*" (http://agricoop.nic.in/bamboo/bamboomission.htm).

Among the ~130 wild and cultivated bamboo species reportedly occurring in India (Sharma, 1987), thorny bamboo or *Bambusa bambos* (L.) Voss is perhaps the most important in the rural areas of Kerala. Despite its economic value and importance and its relatively high biomass production potential (Scurlock et al., 2000), little is known about their ecology, especially the primary productivity and nutrient cycling (Tripathi and Singh, 1994). A few workers however, have estimated the total standing biomass by multiplying the number of culms with the average total aboveground biomass (15 to 25 sample culms; Chandrashekara, 1996; Shanmughavel and Francis, 1996; Shanmughavel et al., 2001). Complete harvesting of the thorny bamboo clumps has been seldom attempted in biomass estimation studies, partly because of the laborious and time-consuming nature of felling whole clumps. Yet, this is important in view of the variability in size, age and biomass accumulation of individual culms in a particular clump. Furthermore, most rural bamboos are

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grown on marginal lands with little or no inputs. Consequently, the values reported for input intensive production systems (e.g., fertilized and irrigated tissue-cultured bamboo; Shanmughavel and Francis, 1996) and/or mixed teak-bamboo system (Chandrashekara, 1996) seldom reflect the productivity of bamboos in the homegardens.

Short rotation tropical plantations that couple intensive management and rapid growth rates are also characterised by high rates of nutrient removal in the harvested biomass. The associated high nutrient export potential, especially with whole tree harvesting, may deplete the site nutrient capital (Kumar et al., 1998). This, in turn, raises concerns about long-term site quality and sustainable production. However, only few attempts have been made to characterise the magnitude of nutrient losses associated with thorny bamboo. Our objectives were to determine the biomass production potential of *B. bambos* with particular reference to the farmlands of central Kerala. We also developed allometric relationships for predicting stand biomass (aboveground) and culm number for thorny bamboo, besides assessing the relative contribution of different components to stand biomass production and estimating the nutrient characteristics of this species.

Materials and methods

To estimate the biomass production potential of bamboo clumps, nine clumps were destructively sampled during February to April 2005. The clumps (diameter ranging from 6.9 to 13.5 m) were selected randomly from a bamboo hedgerow established during June 1985 at Vellanikkara, Thrissur (10°13' N; 76°13' E; 40 m above sea level). Vellanikkara experiences a warm humid climate, having a mean annual rainfall of 2824 mm, most of which falls during south west monsoon (June to August). The mean maximum temperature ranges from 28.5 to 36.7°C. The selected clumps were felled at ground level after measuring its girth at breast height (GBH)—cutting the overhanging and intertwined thorns preceded this (Fig. 1a). After felling, the thorns+leaves were separated, culm-wise (Fig. 1b), followed by measurement of the total height and girth at breast height (GBH) of individual culms (Fig 1c). Fresh weights of all

a

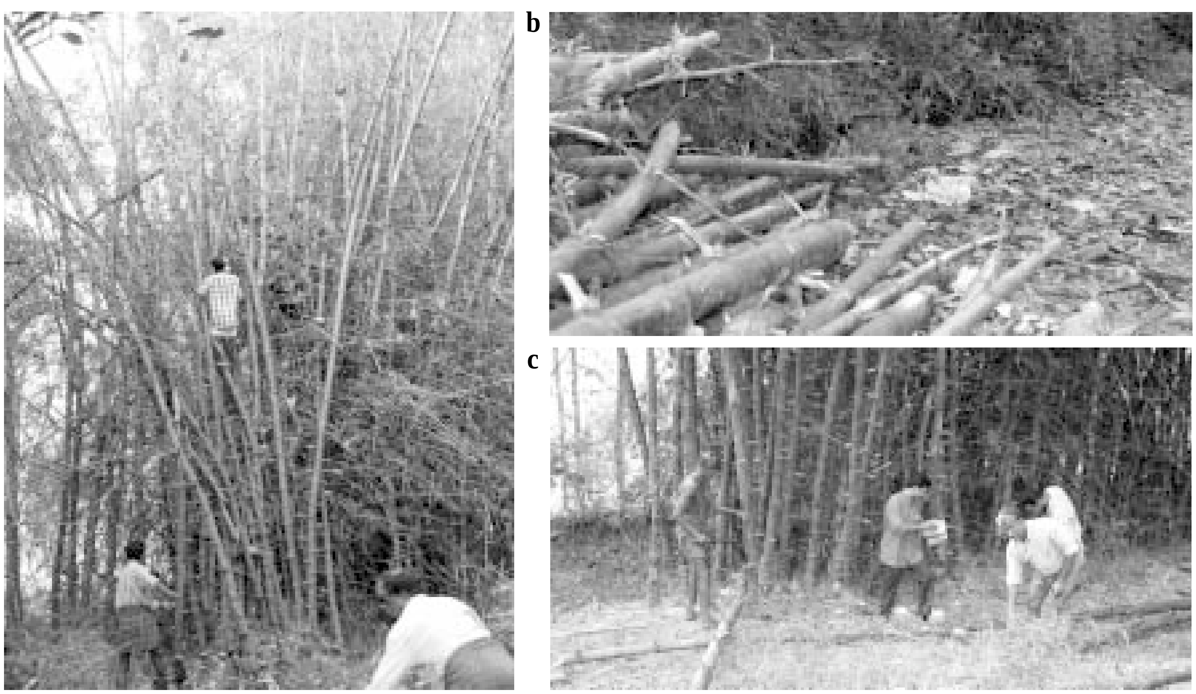

Fig. 1. a. Felling thorny bamboo hedgerows at Vellanikkara in progress , (b) Culms and thorns after separation , (c) Measuring the culm length and diameter

aboveground components (live culms, dead culms and thorns+leaves) were recorded immediately after felling using appropriate spring scales (to either nearest 0.1 kg or 10 mg). Representative culm and foliage+thorn samples (ca 500 g each) were collected (clump-wise in triplicate) for moisture estimation and chemical analyses, randomly. The samples were immediately transferred to the laboratory in double-sealed polythene bags. After recording the fresh weights, they were dried to constant weights at 80°C and ground to pass through a 2-mm sieve. Estimates of dry weight biomass were obtained from the fresh weights of various tissue-types and their moisture contents. Biomass accumulation per clump was then extrapolated to per ha basis by multiplying with 100, assuming a spacing of 10 x 10 m (KAU, 2002).

In addition, to estimate the litter accumulation on the floor, 27 litter samples were collected from the field during April 2005. For this, 1 m^2 grids were randomly placed on the ground. The accumulated litter within the grid was carefully removed and their fresh weights determined using spring scales. Representative litter samples were collected from each grid and kept in a hot air oven at 80°C until constant weights for moisture determination and chemical analyses.

Triplicate samples (live culms, dead culms, thorns+ leaves and litter) were analysed for N, P and K. Nitrogen was estimated following the micro-Kjeldahl method. Phosphorus and potassium were estimated after digesting the samples in diacid mixture (HNO_3 and $HClO_4$ in 9:4). Phosphorus was determined following the vanado-molybdo phosphoric yellow colour method and K by flame photometry (Jackson, 1958). Nutrient removals in bamboo tissue-types (culms, thorns and leaves) were obtained as the product of each component biomass and the average nutrient concentrations in that component. Totals for whole clump were obtained by summing up the values for the components. Nutrient accumulation per clump was then extrapolated to per ha basis by multiplying with the recommended clump density of 100 ha^{-1}. Allometric equations were fitted to predict the total aboveground biomass of clumps as a function of diameter at breast height (DBH) in MS-Excel. Equation for predicting the number of culms in a clump from clump diameter was also developed. For this, a total of 106 bamboo clumps in the farmer's plots of Thrissur district was additionally sampled by measuring the girth at breast height and counting the total number of culms.

Results and discussion

Standing stock of biomass and mean annual production

A comparison of the data presented in Table 1 indicates

Table 1. Biomass production of different tissue-types in nine randomly selected 20 year-old bamboo clumps at Vellanikkara, Kerala

Clump No.	Clump GBH (m)	Number of culms		Biomass yield (kg dry weight $clump^{-1}$)			
		Live	Dead	Live culms	Dead culms	Thorns+leaves	Total
1	6.9	43	26	1000	114	215	1329
2	13.6	87	22	3481	118	419	4018
3	12.9	112	19	3978	60	599	4637
4	13.5	108	32	4194	193	598	4985
5	12.2	46	17	1811	100	270	2181
6	8.4	28	6	1105	35	153	1293
7	7.1	13	6	416	35	89	540
8	8.7	23	10	859	58	176	1093
9	13.5	32	92	1082	384	212	1678
Mean	10.76	54.67	25.56	1992	122	303	2417
SD	2.91	37.67	26.44	1475.2	110.3	190.2	1674

SD= standard deviation, GBH= girth at breast height; thorns+leaves, live culms and dead culms were having mean moisture contents of 40.99±1.79, 48.62 ±2.2 and 27.17±4.72 % respectively that clump biomass production of hedgerow-planted thorny bamboo was variable depending on the size of the clumps, which in turn, determines the number of culms and their biomass accumulation. Total above-ground ranged between 540 and 4985 kg per clump with a mean value of 2417 kg per clump. About 64 to 87% of this, however, was in the live culms (416 to 3978 kg). Previously Shanmughavel et al. (2001) also reported that about 81% of the biomass was contributed by culms. Dry weights of thorns+leaves ranged from 89 to 599 kg per clump. Weight of dead culms was modest (1 to 6% of the total biomass), except for one clump with an unusually high proportion (23% of the total mass) of dead culms—clearly an outlier, and it was excluded in the regression models described subsequently.

Table 2. Total aboveground production, litterfall yield, litter nutrient concentrations and associated nutrient return through litterfall in a 20 year-old thorny bamboo stand at Vellanikkara, Kerala

Parameter	Mean	SD	Max	Min
Total aboveground biomass production (Mg dry weight ha^{-1})‡	241.7	167.4	498.5	54.0
Leaf litter accumulation (g m^{-2})	909	88.7	1130.0	755.0
Elemental concentrations (mg g^{-1})				
Thorns+leaves				
N	7.79	1.21	9.78	6.27
P	0.93	0.1	1.04	0.79
K	8.73	0.7	9.23	6.99
Live culms				
N	3.87	0.26	4.31	3.53
P	0.48	0.13	0.67	0.25
K	6.71	0.56	7.57	5.76
Dead culms				
N	2.57	0.63	3.53	1.76
P	0.17	0.06	0.3	0.12
K	5.14	0.64	6.03	3.79
Leaf litter				
N	5.29	0.397	5.88	4.70
P	0.40	0.029	0.44	0.36
K	4.73	0.195	5.12	4.48
Nutrient return through litterfall (g m^{-2})				
N	48.15	6.53	59.78	39.10
P	3.67	0.51	4.75	2.72
K	42.98	4.34	46.90	36.80

SD= standard deviation ‡for 100 clumps at 10 x 10 m spacing

Total aboveground biomass accumulation (per ha basis) of *B. bambos* clumps at 20 years of age ranged from 54 to 499 Mg ha^{-1} with a mean of 241.7 Mg ha^{-1} (Table 2). This works out to an annual increment of 12.1 Mg ha^{-1} yr^{-1}, which is much lower than the value (47.8 Mg ha^{-1} yr^{-1}) reported by Shanmughavel et al. (2001) for six-year-old tissue-cultured stock of *B. bambos* with fertilization and irrigation in Tamil Nadu. Nonetheless, this is clearly higher than the values reported by many other authors. For instance, Christanty et al. (1996) reported an annual aboveground biomass increment of 7.53 Mg ha^{-1} yr^{-1} for six year-old *Gigantochloa ater* and *G. verticiliata* in a *talun-kebun* system of Java, Indonesia and Tripathi and Singh (1994) showed a value of 9.48 Mg ha^{-1} yr^{-1} for five-year-old *Dendrocalamus strictus* in the dry savanna sites of eastern UP, implying considerable site-, species- and age-related variations. The present value, however, falls within the range reported for nine tropical dicot trees in Kerala (2.6 and 37 Mg ha^{-1} yr^{-1} for 8.8 year-old *Leucaena leucocephapla* and *Acacia auriculiformis* respectively; Kumar et al., 1998).

Nutrient concentrations and nutrient export through harvest

Nutrient removal at harvest from the site depends on both nutrient concentration of different tissue fractions and biomass yield. Nutrient concentrations were found to vary markedly among the clumps and tissue types studied (Table 2). In general, mineral element concentration of tissue types decreased in the order: thorns+ foliage>live culms>dead culms. Highest nutrient accumulation, however, was observed in live culms, followed by thorns+leaves and dead culms (Table 3). Such a trend was reported for other bamboo species too (e.g., Rao and Ramakrishnan, 1989 for *Dendrocalamus strictus* and *D. hamiltonii*). Litterfall N, P and K concentrations were generally greater than that of culm biomass, which indicates that a significant amount of nutrients absorbed by the bamboo plants are recycled. Mean N, P and K concentration in the litter ranged from

4.7 to 5.9, 0.36 to 0.44 and 4.5 to 5.1 mg g^{-1} respectively. Mean litter accumulation on the forest floor was 909 g m^{-2} and the associated nutrient return being 48.2, 3.7 and 43.0 g m^{-2} of N, P and K respectively.

Results of the present study also indicate that the contents of major elements declined in the order K>N>P for twigs, live culms and dead culms. Previous workers too observed significant K accumulation in bamboo biomass and highlighted its ecological significance (Rao and Ramakrishnan, 1989). Nutrient accumulation and export from the site, however, have become an important consideration in short-rotation, high-yield plantation systems, where nutrients removed through frequent harvests may exceed the natural rates of nutrient inputs such as mineral weathering, atmospheric inputs and biological fixation (Kumar et al., 1998). Needless to mention that fast growing species such as bamboo may result in marked loss of nutrients from the site (approximately 922, 122 and 1440 kg N, P and K ha^{-1} respectively), especially if whole clump harvesting is resorted to.

Allometric equations

Allometric equations were fitted for the first time, to our knowledge, linking whole clump dry weight with clump DBH and number of culms/clump with DBH for thorny bamboo (Fig 2). The fitted equations gave relatively high R^2 values and the residual plots also did not indicate any bias, implying that the equations reported here give reasonably good predictions of culm number per clump and standing stock of clump biomass. The three equations for predicting culm number, total clump biomass and live culm biomass are as follows:

$$Y = -3225.8+1730.4\ DBH\ (R^2 = 0.83;\ n=8;\ p<0.001) \quad [Eq.\ 1]$$

$$\ln Y_l = 4.298 + 2.647 \ln DBH\ (R^2 = 0.82;\ n=8;\ p<0.001) \quad [Eq.\ 2]$$

$$Y_n = -12.23+37.281\ DBH\ (R^2 = 0.80;\ n=106;\ p<0.0001) \quad [Eq.\ 3]$$

Where *Y* is the total biomass per clump and *DBH* is the clump diameter at breast height (m), Y_l is the live culm dry weight (kg) and Y_n is no. of culms.

In conclusion, thorny bamboos accumulate substantial aboveground biomass, especially in the culms (~82% of the total). Mean annual aboveground biomass increment at a clump age of 20 years was 12.1 Mg ha^{-1} yr^{-1}. Implicit in this is not only a high C sequestration potential but also its relatively long-term storage in the culms. Conversion of degraded or marginal lands to bamboo-based production systems can thus result in major benefits. Whole clump harvesting, however, may lead to considerable nutrient export from the site; especially K. For a clump density of 100 ha^{-1}, nutrient removal through

Table 3. Nutrient removal through harvest of 20 year-old thorny bamboo clumps at Vellanikkara, Kerala

Statisitc	Nutrient removal (kg $clump^{-1}$)‡											
	Thorns + foliage			Live culms			Dead culms			Total		
	N	P	K	N	P	K	N	P	K	N	P	K
Mean	2.46	0.30	2.69	6.41	0.90	11.08	0.35	0.022	0.65	9.22	1.22	14.4
SD	1.75	0.21	1.80	4.76	0.83	8.22	0.39	0.017	0.53	6.38	1.03	10.0
Max	5.86	0.62	5.61	14.20	2.41	24.4	1.35	0.054	1.86	19.04	3.06	31.0
Min	0.59	0.07	0.82	1.34	0.13	2.25	0.10	0.004	0.17	2.04	0.21	3.25
	Nutrient removal (kg ha^{-1})‡											
Mean	246	30	269	641	90	1108	35	2.2	65	922	122	1440
SD	175	21	180	476	83	822	39	1.7	53	638	103	1000
Max	586	62	561	1420	241	2440	135	5.4	186	1904	306	3100
Min	59	7	82	134	13	225	10	0.4	17	204	21	325

SD= standard deviation; ‡ n=9; ‡for 100 clumps at 10 x 10 m spacing

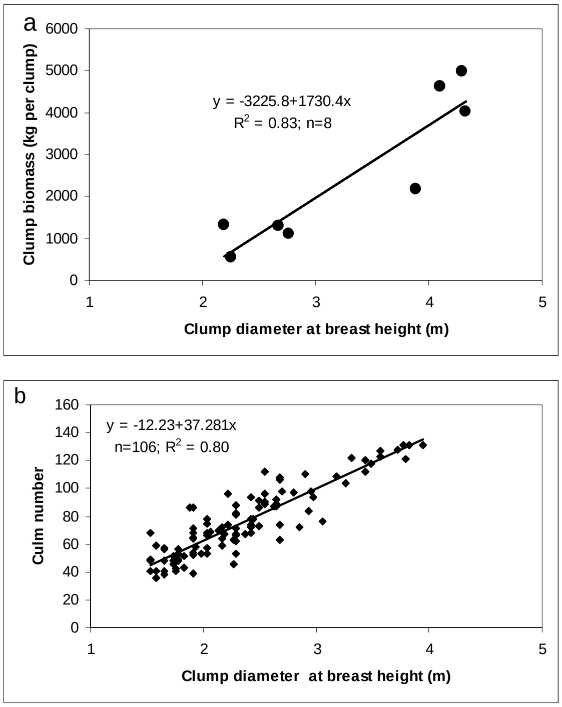

Fig. 2. Allometric relationships linking clump dry weight with DBH (*a*) and culm number with clump diameter (*b*) in thorny bamboo at Vellanikkara, Thrissur

harvesting the aboveground portion was estimated as 922, 122 and 1440 kg N, P and K ha^{-1} respectively. About 27% N, 25% P and 19% K of the aboveground nutrient accumulation, however, will be returned to the site if leaves and small twigs are left on the site after harvesting. Litterfall represents another route through which nutrient return occurs from the living clumps. Mean litterfall accumulation in the present study was 909 g m^{-2} and the associated nutrient return being 48.15, 3.67 and 42.98 of N, P and K g m^{-2} respectively.

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