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Bambusa bambos (L.)Voss plantation in eastern India: I. Culm recruitment, dry matter dynamics and carbon flux

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Abstract: Culm recruitment, standing biomass, net production, litterfall, floor litter mass and carbon flux were estimated at the age of 3, 4 and 5 years in a *Bambusa bambos* plantation in the northwest alluvial plains of Bihar, India.The number of culms produced per clump varied from 22 to 31. The recruitment to culm population varied between 16 and 21 per cent and shoot mortality between 3 and 5 per cent per year. Net accumulation of green culms between third and fourth year was 675 and between fourth and fifth year 975 ha^{-1}. The total biomass was 170.8 Mg ha^{-1} in 3-year-old to 257.3 Mg ha^{-1} in 5-year-old plantation contributed by culms (65%), branches (21%) and leaves (4%). Total net primary production (NPP) ranged between 44.6 Mg ha^{-1} year^{-1} (4-year-old) and 60.5 Mg ha^{-1} year^{-1} (5-year-old), of which aboveground net production was 41.2 to 55.6 Mg ha^{-1} year^{-1} (between 3-4, and 4-5 years, respectively). Short-lived components (leaves and roots) contributed about 20 per cent of net production of bamboo. Annual litterfall increased with the age of the plantation from 5.06 Mg ha^{-1} (3-year-old) to 6.94 Mg ha^{-1} (5-year-old). Percentage contribution of leaf and woody litter varied between 89 and 91 and, 9 and 11 respectively. The bulk of litterfall (80-89%) occurred during winter season (November to February). The mean litter mass on the bamboo plantation floor ranged from 3.2 to 4.0 Mg ha^{-1}. Turnover rate for litter ranged from 0.77-0.80. The total carbon storage in standing biomass of 4- and 5-year-old plantation varied from 83.3 to 103.8 Mg ha^{-1}, of which 68 per cent was distributed in culms, 21 per cent in branches, 20 per cent in leaves and 9 per cent in belowground biomass. A substantial amount of carbon varying from 2.3 (4-year-old) to 2.8 Mg ha^{-1} year^{-1} (5-year-old) was transferred to soil through litterfall and root.

Key words: Biomass, litter, net primary productivity, carbon budget.

INTRODUCTION

In India, bamboo provides almost the entire supply of long fibre pulping material for the pulp and paper industry and at present, there is a shortage of raw material. Therefore, bamboo cultivation needs greater emphasis in present day farming. About 23 genera and over 100 indigenous species of bamboo are available in India (Jain

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and Biswas, 2001) and are grown over an area of 10.05 million hectares or about 12.8 per cent of the total forest area of the country (Shanmughavel *et al*., 2002).

Despite being an important source of many utility products including fuel, fodder and small timber, our knowledge on biomass accumulation, primary productivity and carbon deposition of bamboo is scanty (Christanty *et al*., 1996; Tripathi and Singh, 1996; Shanmughavel *et al*., 2002). Plantations are often favoured for carbon sequestration because of their ability to accumulate large amounts of organic matter in woody biomass and decay resistant litter. The objectives of this study were (i) to estimate annual rates of recruitment and mortality of *Bambusa bambos* (L.) Voss, (ii) to develop regression equations to estimate bamboo biomass and (iii) to estimate aboveground and belowground net primary productivity (in terms of carbon and dry matter).

MATERIALS AND METHODS

Study Site

The study was carried out at the bamboo plantation located in Rajendra Agricultural University, Pusa (Samastipur), Bihar, India (25°59' N latitude and 85°48' E longitude) at an altitude of 52.6 m asl. The climate is sub-tropical monsoonal with three distinct seasons, *viz.*, rainy (July-October), winter (November-February) and summer (March-June). The annual average rainfall during the study period was 1129 mm with most of the rain (87%) falling between June and September. The maximum and minimum temperature ranged from 22.8°C (January) to 34°C (June) and 10.2°C (January) to 27.2°C (July), respectively. The soil is sandy loam (sand, silt, and clay at the rate of 56, 35, and 9%, respectively), alkaline (pH 8.3) and classified as Illitic Ustic Typic Calciorthent. The soil contained 0.36 per cent organic carbon, 40.0 kg ha^{-1} available P_2O_5, 240 kg ha^{-1} available K_2O and 35 per cent free $CaCO_3$ prior to planting.

Stocking density and plant biomass

Plantation of *B. bambos* was raised in March 1997 by planting 6-month-old nursery-raised seedlings in pits (45 cm x 45 cm x 45 cm) at a spacing of 6 m x 6 m with a total of 250 seedlings ha^{-1}. Three plots, each 25 m x 25 m in size, were established in 2000. Number of bamboo clumps per plot varied from 15 to 17. Five clumps in each plot were randomly selected and marked with paint. The number of culms in these selected clumps was counted annually from 2000 (3-year-old) to 2002 (5-year-old). The bamboo culms were grouped into three categories, namely current year culms, old culms, and standing dead culms. All culms were measured 10 cm above the ground for diameter and grouped into 5-7, 7-9, 9-11, 11-13, and 13-15 cm size classes. Fifteen culms of different size classes (three in each diameter class) were harvested at ground level in December 2000. The height of the culms was determined. The fine root (< 2 mm dia)

Table 1. Constants (a), slopes (b), coefficients of determination (r^2) for regression equations relating biomass (Y, kg per bamboo) to culm diameter (X, cm) of *B. bambos.* The equation used was Y = a + bX

Dependent variables (Y)	a	b	r^2	*p*
Leaf	0.404	0.060	0.62	<0.01
Branch	2.963	0.431	0.69	<0.01
Culm	3.769	1.865	0.97	<0.01
Rhizome	0.455	0.257	0.80	<0.01
Root	0.123	0.012	0.58	<0.01

biomass was estimated in 12-15 soil monoliths (each 15 cm x 15 cm, 60 cm deep) excavated at three distances (50, 150, 250 cm) from the clump base and washed over a sieve system. Rhizomes of these culms were also excavated. Coarse root samples (> 2 mm dia), obtained by excavation of entire clump root systems, were bulked per clump. Fresh weights of leaves, branches, culms, rhizomes and roots were taken in the field. Sub-samples (each 100-500 g fresh weight, composed of upper, middle and lower strata of culm, branch, rhizomes, roots and leaves) were collected in polythene bags, transported to the laboratory and oven dried at 80°C for 24 h to a constant weight. Least squares regression equations were developed to estimate dry weight of each component from culm diameter (Table 1). Biomass for each component for each size class was multiplied by the number of culms in that size class. Summation of values across size classes yielded total biomass, which was calculated separately for each year. The biomass values were multiplied by the density in the respective diameter classes in each plot and averaged.

Net productivity

Net primary production (NPP) was calculated for the 2000-2001 (4-year-old), and 2001-2002 (5-year-old) growth cycles separately from foliage and current culm biomass and net biomass accumulation in different components using the following expression given by Singh and Singh (1999):

$$NPP_n = FB_n + CSB_n + \Delta\ OSB + \Delta\ DSB + \Delta\ RhB + \Delta\ RB + NLL_n$$

where, NPP_n = net primary production in n^{th} year; FB_n = foliage biomass in n^{th} year; CSB_n = current culm biomass in n^{th} year; ΔOSB = change in old stem biomass between n-1 and n^{th} year, ΔDSB = change in dead shoot biomass between n-1 and n^{th} year; ΔRhB = change in rhizome biomass between n-1 and n^{th} year; ΔRB = change in root biomass between n-1 and n^{th} year and NLL_n = non-leaf litter deposited in n^{th} year.

Litterfall and litter mass

Litterfall was recorded at each plot by randomly placing four perforated wooden litter traps of size 50 cm x 50 cm x 15 cm fitted with nylon net at the bottom. Periodic litter collections from the trap were made round the year at monthly intervals. The samples were brought to the laboratory and separated into leaf and woody litter. Litter in each category was oven-dried for 24 h at 80°C and weighed.

Data for the floor material of all the three plots were recorded from ten 50 cm x 50 cm randomly placed quadrats at four months interval, once in each season, *i.e.*, rainy, winter and summer. The material on the plantation floor was then collected and categorized into: (a) fresh leaf litter, (b) partly decomposed litter (including highly fragmented material mixed with soil recovered by floatation in water of the top 1 cm layer of soil) and (c) wood litter. The collections were brought to the laboratory separately and oven dry weights were recorded.

The turnover rate (k) of litter was calculated following the methods of Tripathi and Singh (1996) as $k = A/(A+F)$, where A is the annual litterfall and F is the mass of litter at steady state. Turnover time (t) is the reciprocal of turnover rate and expressed as $t = 1/k$. In the present study, the F values were calculated on the basis of partly decomposed litter during the winter season.

Carbon concentration determination

Three soil samples were collected at random from each of the three permanent plots during October in 2000, 2001 and 2002 from four depths (0-15, 15-30, 30-45, 45-60 cm). The samples from within a plot were thoroughly mixed to yield one composite sample per plot. Large pieces of plant materials were removed and the soil was sieved through a 2 mm mesh screen.

Organic C in soil was determined in triplicate by dichromate oxidation and titration with ferrous ammonium sulphate (Moore and Chapman, 1986). Carbon concentration in different components of bamboo was determined in triplicate using a CHNS/O-Analyser (Perkin Elmer Series II-2400). The carbon storage and flux in the plantation were computed as the products obtained by multiplying dry weight of biomass and productivity values of different components by their mean carbon concentrations.

Statistical analysis

The data were subjected to least squares regression analysis and ANOVA using the Statgraphics package (Statistical Graphics Corporation, 1986).

Table 2. Distribution of green and dead culms in different diameter classes of *B. bambos* plantation

Plantation	No. of culms (ha^{-1} ± SE)					
	Diameter class (cm)					
	5-7	7-9	9-11	11-13	13-14	Total
3-year-old						
Current	125±20	250±32	200±22	0	0	575±37
Old	500±25	625±31	1250±25	925±26	275±33	3575±95
Green	625±15	875±14	1450±32	925±14	275±20	4150±77
Dead	600±21	475±25	250±19	0	0	1325±38
Total	1225±45	1350±52	1700±62	925±22	275±18	5475±63
4-year-old						
Current	200±25	325±38	250±18	0	0	775±41
Old	500±31	825±41	1300±54	1050±59	375±32	4050±68
Green	700±41	1150±59	1550±53	1050±51	375±28	4825±99
Dead	750±39	500±22	250±9	0	0	1500±41
Total	1450±47	1650±53	1800±58	1050±53	375±31	6325±80
5-year-old						
Current	300±27	425±28	350±29	0	0	1075±56
Old	625±47	900±25	1500±59	1200±61	500±27	4725±72
Green	925±53	1325±73	1850±67	1200±57	500±31	5800±77
Dead	800±51	650±32	375±27	0	0	1825±52
Total	1725±97	1975±103	2225±77	1200±48	500±27	7625±75

RESULTS

Culm dynamics

Distribution of green and dead culms in different diameter classes, for third, fourth and fifth year is given in Table 2. The majority of green culms was in the 9-11 cm diameter class, while the dead culms, which averaged 24 per cent of the total culms, dominated in the 5-7 cm class. Of the total culms, 11-14 per cent was represented by current year culms and 62-65 per cent by old culms. The recruitment to culm population was 850 ha^{-1} between the third and fourth year, and 1300 ha^{-1} between the fourth and fifth year. Corresponding values for mortality were 175 culms ha^{-1} and 325 culms ha^{-1}; this resulted in net accumulation of 675 green culms between the third and fourth year and 975 green culms ha^{-1} between the fourth and fifth year. The number of culms in each clump varied between 22 and 31. Culm diameter and height ranged from 5.5 to 14.8 cm and 1.5 to 16.5 m respectively. Recruitment of new culms occurred during the rainy season.

Biomass

Total biomass increased from 170.8 Mg ha^{-1} in the 3-year-old to 257.3 Mg ha^{-1} in the 5-year-old plantation of *B. bambos* (Table 3). ANOVA indicated significant differences due to age in the biomass of branches, current year culm, old culm, rhizome and total biomass. For the dead culm, only the fifth year biomass was significantly different from that of the previous years. Foliage and root biomass showed no significant

Table 3. Oven-dry biomass (Mg ha^{-1} ± SE) of *B. bambos* plantation at different ages

Components	3-year-old	4-year-old	5-year-old
Foliage	8.11±0.72	9.18±1.41	11.09±1.35
Branch	36.85±6.53	44.18±4.54	54.61±10.92
Current year culm	10.50±2.15	15.01±1.37	21.51±3.45
Old culm	77.03±5.16	91.96±4.52	111.15±23.2
Dead culm	22.30±3.18	26.87±3.08	34.54±10.44
Total culms	109.83±24.33	133.84±34.81	167.20±45.05
Rhizome	14.76±2.61	18.01±3.74	22.52±8.81
Root	1.25±0.73	1.49±0.57	1.83±0.72
Total	170.80±45.32	206.70±51.23	257.25±75.23

Table 4. Distribution of biomass (Mg ha^{-1} ± SE) in different size classes of current, old and dead culms of *B. bambos* plantation at different ages

Year	Biomass (Mg ha^{-1}) Culm diameter class (cm)					
	5-7	7-9	9-11	11-13	13-14	Total
3-year-old						
Current	1.78±0.22	4.39±0.26	4.33±0.35	0	0	10.50±2.21
Old	7.11±0.67	10.98±0.78	27.09±1.25	23.84±2.12	8.01±0.35	77.03±2.26
Dead	8.53±1.23	8.35±1.27	5.42±0.72	0	0	22.30±1.04
Total	17.42±2.07	23.72±2.65	36.84±2.35	23.84±2.12	8.01±0.35	109.83±4.87
4-year-old						
Current	3.07±0.32	6.38±1.08	5.56±0.85	0	0	15.01±0.87
Old	7.67±1.54	16.19±1.53	28.90±1.65	27.85±1.85	11.35±1.23	91.96±4.97
Dead	11.50±2.10	9.81±2.09	5.56±0.23	0	0	26.87±0.88
Total	22.24±3.65	32.38±3.32	40.02±2.42	27.85±1.85	11.35±1.23	133.84±5.61
5-year-old						
Current	4.77±1.02	8.50±0.86	8.24±1.99	0	0	21.51±1.05
Old	9.93±1.89	18.00±1.16	35.31±1.49	32.50±1.58	15.41±1.16	111.15±3.69
Dead	12.71±1.62	13.00±0.56	8.83±2.22	0	0	34.54±1.25
Total	27.41±3.65	39.50±2.08	52.38±2.54	32.50±1.58	15.41±1.16	167.20±6.32

differences in the third and fourth year, but in the fifth year, biomass values were significantly higher as compared to the biomass in the previous years.

The contribution of different components of the bamboo to total stand biomass was remarkably consistent across the three ages. Most of biomass was contributed by live culms (51.5%) followed by branches (21.4%), rhizomes (8.7%), foliage (4.5%) and roots (0.7%). Thus, 90.6 per cent of the biomass was aboveground and 9.4 per cent belowground. There was a marked variation in the distribution of biomass in the stems of different diameter classes (Table 4). In the current year culms, a majority of biomass (80.1%) resided in the 7-9 and 9-11 cm diameter classes, while the 9 -11 and 11-13 cm diameter classes harboured most of biomass (62.9%) in the old culms. Most of the biomass (76.5%) in the dead culms was accounted by the diameter classes, 5-7 cm and 7-9 cm. Within the culm components, greatest accumulation in biomass occurred in old culms.

Litterfall, floor mass and turnover

The total annual litterfall increased with the age of the plantation (Table 5). Percentage contribution of leaf and woody litter varied from 89-91and 9-11, respectively. The bulk of litterfall (80-89%) occurred during winter season, whereas the lowest values were recorded during the rainy season. The seasonal mean total floor litter mass increased with the age of the plantation (Table 6). Plantation floor showed the highest fresh leaf litter mass during rainy season. On the other hand, the quantity of partly decayed litter mass was the highest in rainy season, and the lowest in summer season. Such fluctuations reflected a response of two simultaneously operating processes; transfer of fresh litter into this category and rapid decomposition of the litter material. The turnover rate (*k*) of litter varied from 0.77 (5-year-old) to 0.80 (3-year-old plantation). The turnover time, which was the reciprocal of turnover rate, varied between 1.25 and 1.30 years (Table 5).

Net primary production

Net primary production (NPP) could be calculated only for the fourth and fifth year (Table 7). The total NPP of the 5-year-old plantation was greater than that for the 4-year-old plantation. Net production of each component (foliage, branch, current

Table 5. Litterfall (Mg $ha^{-1}year^{-1} \pm$ SE), turnover rate (*k*) and turnover (*t*, year) of litter under *B. bambos* plantation

Age (years)	Litterfall				
	Leaf	Non-leaf	Total	*k*	*t*
3	4.62±0.84	0.44±0.03	5.06±1.05	0.80	1.25
4	5.08±1.23	0.63±0.03	5.71±1.23	0.79	1.27
5	6.18±1.97	0.76±0.08	6.94±1.87	0.77	1.30

Table 6. Floor litter biomass and turnover of litter in *B. bambos* plantation (Mg ha^{-1} ± SE)

Age (years)	Floor litter component	Rainy	Winter	Summer
3	Fresh leaf litter	0.12±0.002	1.58±0.078	2.20±0.095
	Partly decayed litter	1.60±0.051	1.27±0.023	0.55±0.001
	Wood litter	0.74±0.003	0.72±0.005	0.75±0.005
	Total	2.46±0.083	3.57±0.088	3.50±0.073
4	Fresh leaf litter	0.16±0.003	1.62±0.065	2.28±0.073
	Partly decayed litter	1.70±0.031	1.52±0.027	0.82±0.006
	Wood litter	0.76±0.005	0.74±0.008	0.76±0.003
	Total	2.62±0.095	3.88±0.086	3.86±0.072
5	Fresh leaf litter	0.22±0.004	1.82±0.041	2.34±0.078
	Partly decayed litter	2.10±0.082	2.07±0.031	1.10±0.005
	Wood litter	0.79±0.006	0.75±0.005	0.78±0.003
	Total	3.11±0.092	4.64±0.071	3.99±0.094

year culm, old culm, dead culm, rhizome and root) was significantly higher for the fifth year compared to the fourth year. For both the years, culm contributed the maximum (54.5%) to NPP followed by foliage (19.5%), branch (16.8%), rhizome (7.4%) and root (0.9%). The current culms accounted for 18.8 to 19.5 per cent, old culms 57.5 to 62.2 per cent, and dead culms 19 to 23 per cent of culm production.

Table 7. Net primary production (Mg ha^{-1} year^{-1}) of different components and total plantation of *B. bambos*

Components	Age (years)	
	4	5
Foliage	9.18±1.52	11.09±2.72
Branch	7.33+1.25	10.43±1.25
Current shoots	4.51+0.58	6.50±0.23
Change in old culm	14.93±3.58	19.19±2.43
Change in dead culm	4.57±1.26	7.67±2.41
Total culms	24.01±3.21	33.36+3.83
Change in rhizome	3.25±0.28	4.51±0.51
Change in root	0.24±0.02	0.34±0.04
Non-leaf	0.63±0.05	0.76±0.03
Total	44.64±3.68	60.49±4.54
BAR*	4.63	4.25

* Biomass accumulation ratio (biomass/net production).

Carbon budget and flux

Carbon concentrations varied in different components. The mean concentrations were: bamboo leaf 37.2 per cent, branch 39.1 per cent, culm 42.3 per cent, rhizome 40.6 per cent, and root 39.2 per cent. The dry matter values for standing biomass, net production, litterfall, floor biomass and soil were converted to the carbon equivalent by multiplying the respective value of dry matter with their mean concentration (Fig.1). This model shows the mean quantities of carbon stored in bamboo components and the net amounts transferred between components annually in 4- and 5-year-old bamboo plantation. The total quantities of carbon in the standing biomass of bamboo were: 83.3 Mg ha^{-1}

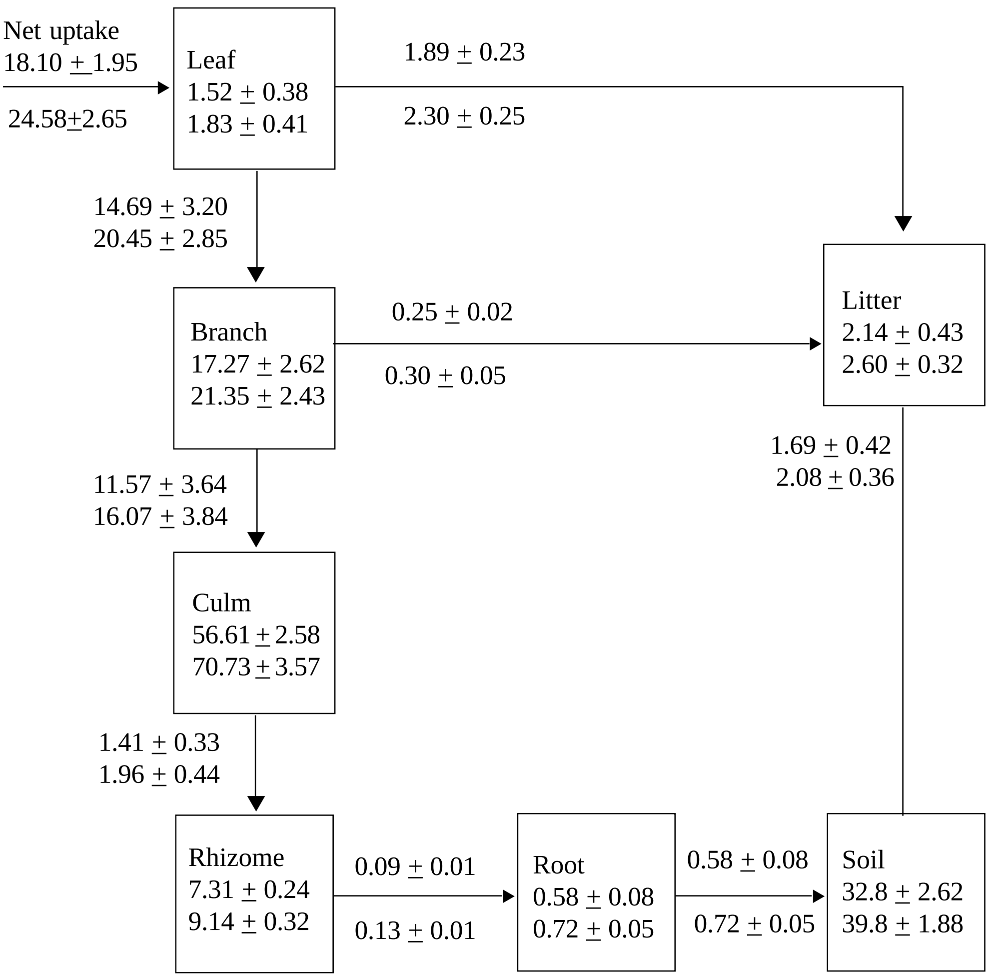

Figure 1. Diagrammatic representation of annual carbon budget for *B. bambos* plantation. Upper values are for the 4-year-old and lower values for the 5-year-old plantation. Values inside compartments show carbon content (Mg ha^{-1}± SE). Net annual fluxes between the compartments are given on the arrows (Mg ha^{-1} $year^{-1}$± SE). The difference between input and output of each compartment represents the quantity of carbon incorporated in that compartment.

in 4-year-old and 103.8 Mg ha^{-1} in 5-year-old plantation, distributed 68 per cent in culm, 21 per cent in branch, 2 per cent in leaves and 9 per cent in belowground biomass.

Organic carbon storage in soil to a depth of 60 cm is higher in older bamboo plantation than in younger ones. Both the values of organic carbon (0.42 and 0.51%) in 4- and 5-year-old bamboo plantation were higher as compared to initial value (0.36%). This increase is associated with the incorporation of the partly decomposed (fragmented) litter and the death of bamboo fine roots. Inputs of organic carbon to soil from aboveground and belowground parts were estimated as the annual production of litter/root and their corresponding turnover rates. In the case of roots, a conservative turnover rate of one was assumed. Thus, substantial amounts varying from 2.27 Mg ha^{-1} year^{-1} (4-year-old) to 2.80 Mg ha^{-1} year^{-1} (5-year-old) of carbon were transferred to soil through litterfall and root.

DISCUSSION

The production of new culms is linearly related to the number of old culms in a clump, and a majority of new culms is produced by the rhizomes of 1- to 2-year-old culms as reported by Singh and Singh (1999). At a given site, the production of new culms depends mostly on the degree of congestion, the clump age and the rainfall of the previous year (Shanmughavel and Francis, 1999). Singh and Singh (1999) reported an average annual recruitment of culms of *Dendrocalamus strictus* between 18 (between the third and fourth year) and 36 per cent (between the fourth and fifth year) on mine spoil in a dry tropical region. The annual recruitment in the present plantation varied from 16 to 21 per cent. In a mature *D. strictus* plantation, the annual mortality varied between 6.6 and 10.6 per cent (Tripathi and Singh, 1996). The mortality rates recorded in the present study are only 3 to 5 per cent. Thus, the calciorthent soil of Bihar proved favourable to the growth and survival of *B. bambos.*

The quantity of biomass per unit area constitutes the primary inventory data needed to understand the flow of nutrients and water through the ecosystem. The bamboo plantation developed on the calciorthent soil accumulated a substantial amount of biomass and the biomass of each component (Table 3) increased with increasing field age due to increase in both number of culms per hectare and biomass per culm. Several bamboo forests and plantations recorded 26 to 320 Mg ha^{-1} aboveground biomass (Othman, 1992; Tripathi and Singh, 1996; Singh and Singh, 1999; Shanmughavel *et al.*, 2002). The higher accumulation of biomass (150 to 227 Mg ha^{-1}) in *B. bambos* in this study may be due to higher culm recruitment under irrigation. In a dry tropical region, 65 per cent of the total bamboo (*D. strictus*) biomass was allocated aboveground and 35 per cent belowground (Singh and Singh, 1999), compared to 90 per cent and 10 per cent in the present *B. bambos* plantation growing in subtropical monsoonal type of climate.

The productivity of bamboo species in a given site in terms of annual yield depends on the production of new culms every year. The sustainability of yields usually refers to harvesting culms more or less equal to the yearly production of new culms. Total net primary production of the different aged plantation in the present study was found to be higher (44.6 to 60.5 Mg ha^{-1} $year^{-1}$) compared to 20.7 (3-year-old) to 32.0 Mg ha^{-1} (5-year-old) in *D. strictus* plantation (Singh and Singh, 1999). Aboveground net primary production in bamboo forests and bamboo plantations ranged from 1.5 and 24.7 Mg ha^{-1} $year^{-1}$ (Veblen *et al.*, 1980; Taylor and Zisheng, 1987; Tripathi and Singh, 1996; Singh and Singh, 1999) compared to 41.2 to 55.6 Mg ha^{-1} $year^{-1}$ in the present study. The difference in average net production among different bamboo plantations may be partly caused by climate, especially the length of the growing season when both temperature and moisture are favourable.

Biomass accumulation ratio (BAR) has been used to characterize the production in bamboo plantation. It expresses the quantity of biomass retained per unit of net production. The BAR averaged one for foliage, 5.0-5.6 for culm, 5.0-5.5 for rhizome and 5.4-6.2 for roots. As a whole, BAR for the present bamboo plantation varied between 4.3 and 4.6. Isagi (1994) recorded BAR of 6 for culms of *Phyllostachys bambusoides* and this ratio for a temperate bamboo, *Arundinaria falcata,* averaged 11.2 (Pandey, 1990). Lower BAR of bamboo plantation in the present study compared to the above plantations reflects greater production efficiency.

Bamboo leaves usually fall when they are between 12- and 18-month-old, and are quickly replaced by new leaves (Christanty *et al*., 1996). At the age of 3 to 5 years, total litterfall was estimated to be 5.06 to 6.94 Mg ha^{-1} $year^{-1}$. These values are lower than the litterfall production (9.2 to 11.8 Mg ha^{-1} $year^{-1}$) in a *B. bambos* plantation (Shanmughavel and Francis, 1996) and fall within the range of 4.1 to 7.2 Mg ha^{-1} $year^{-1}$ reported by Tripathi and Singh (1994) for mature bamboo savannas in the dry tropics.

Litter layer on the soil surface acts as an input-output system, receiving inputs of organic matter and nutrients from the vegetation, losing biomass by decomposition and supplying nutrients to the mineral soil and roots. Therefore, litter accumulation and decomposition is seen as a key factor for restoring fertility of the soil. The decomposition of plant litter is governed by the interplay of abiotic and substrate quality variables (Das and Chaturvedi, 2003) but very few studies have documented the floor biomass decomposition in bamboo stands, especially in the humid tropics. Tripathi and Singh (1996) reported the turnover rate (k) of the total litter of bamboo plantation as 0.63 to 0.81. In the present study, k values (0.77 to 0.80) fall within this range. The slow decomposition of bamboo leaf litter should lead to soil organic matter build up in the long run and is expected to provide benefits of mulching. Because of the accumulation of leaf mulch, bamboo is efficient in conserving soil moisture (Singh and Singh, 1999).

The total carbon storage in the bamboo plantation soil (33-40 Mg ha^{-1}) was lower than the values of 28-53 Mg ha^{-1} reported in bamboo savanna (Tripathi and Singh, 1996). The soil carbon represented 20 per cent of the total carbon storage in the bamboo plantation with the remaining 80 per cent stored in the phytomass. These values are lower than that reported by Singh and Singh (1999). The quantity of carbon stored in the phytomass was 83.3 to 103.9 Mg ha^{-1}. The rate of carbon fixation in the total net production in bamboo plantation was 11.6 to 16.0 Mg ha^{-1} $year^{-1}$ as reported by Isagi (1994) for *P. bambusoides* in Japan.

CONCLUSION

The present study provides basic information on culm production and biomass accumulation at the third, fourth and fifth year of *B. bambos* plantation growing in calciorthent soil of northwest alluvial plain of Bihar under irrigation. Knowledge of the growth characteristics will assist in the design of prescriptions for the sustainable management of bamboo plantations. This study also shows that addition of carbon through litter and root to the tune of 2.3 (4-year-old) to 2.8 Mg ha^{-1} (5-year-old) protects the soil health from further deterioration. Moreover, carbon dioxide is converted into structural carbon in the plantation. From this study, it appears that the bamboo is able to recover much of the nutrients leached deeper into the soil profile at the age of 4 and 5 years, and to deposit them at or near the soil surface as aboveground litter and dead fine roots. Furthermore, the thick organic layer produced by the bamboo may be very important for conserving soil moisture and minimizing surface run off and erosion, in addition to its nutritional contributions.

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