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Role of active components in carbon and nutrient cycling of bamboo ecosystems in Indian dry tropical region

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Abstract: Dry matter, carbon and nutrient dynamics in mature and harvested stands of bamboo ecosystems in Vindhyan dry tropics were studied with emphasis on the role of active components (*i.e.* leaves, fine roots and herbs). Bamboo harvest resulted in lowering of total net production in bamboo, but increased annual allocation to the belowground components, especially to the fine roots. Active components showed marked seasonality and contributed substantially (86-94%) to the total dry matter, carbon and nutrient additions in the soil. Dry matter, C, N and P additions to the soil by mortality of active components were substantial (90-94% of total additions). This reflects that in the nutrient limited bamboo ecosystems, the active components, because of their marked seasonality and high nutrient use efficiency, play a significant role in maintaining a fairly high net production within a short span of time, despite substantial periodical (5-7 years) nutrient export from the system in harvesting.

Key words: Bamboo ecosystems, active components, nutrient cycling, fine roots, leaf litter, *Dendrocalamus strictus*.

INTRODUCTION

Landuse change has been reported as important global change factor causing changes in the structure and functioning of terrestrial vegetation over the world (Sala *et al.*, 2000; Balmford and Bond, 2005). Landscape transformations are extensively occurring in dry tropical regions and are affecting the pools of carbon and nutrients. Tropical forests play a significant role in the global C and nutrient cycle by affecting the circulation of C and nutrients through rapid turnover rate of organic matter and accumulating their huge amounts in vegetation and soil pools (Brown *et al.*, 1993). Tropical forests are generally known to be limited by P availability in contrast with N limited temperate forests (Vitousek and Sanford, 1986). Recent report suggests that biomass production in many tropical forests is often limited by low soil N and P contents (Ludwig *et al.*, 2004).

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In Indian dry tropical regions, conversion of vast expanses of natural deciduous forests is occurring rapidly into a variety of quasi-stable savanna types and accompanied by massive changes in ecosystem structure and functioning (Singh. 1989 a, b; Tripathi and Singh, 1994). In the Vindhyan plateau region of East Mirzapur Forest Division (U.P.), large-scale plantations of bamboo (*Dendrocalamus strictus* (Roxb.) Nees) were raised five decades ago. Raising of bamboo plantation followed by its periodical harvest at 5-7 years interval has led to the conversion of the forested land into bamboo dominated savanna ecosystem. Each bamboo harvest represents a huge amount of organic matter and nutrient exports from nutrient poor bamboo savanna ecosystem. Rapid re-growth following the harvest makes the bamboo ecosystem highly dynamic from the point of view of its functioning (Tripathi and Singh, 1994).

Most reviews on productivity and nutrient cycling in dry tropical forests exhibit paucity of quantitative information on the role of active components of the ecosystems *viz.* leaves, fine root and herbs (Brown and Lugo, 1982). The present paper emphasizes the significance of active components (leaves, fine roots and herbs) in the functioning of dry tropical bamboo savanna ecosystem.

MATERIALS AND METHODS

Study sites

Two bamboo savanna sites were located in the Marihan Forest Range (24°55' to 25° 10' N lat., 82° 30' to 82° 45' E long.) of the East Mirzapur Forest Division. The region has monsoon climate with three distinct seasons: warm-wet rainy (July-October), cool-dry winter (November-February), and hot-dry summer (March-June). The mean monthly temperature ranges from 17.5°C (January) to 37.5°C (May) and the annual rainfall averages 830 mm, of which 86 per cent occurs in the rainy season. The ultisol soils on both sites are nutrient poor and sandy in texture (sand, silt and clay, 80-90, 5-11 and 1-5%, respectively) with a moderate water holding capacity (25-37%).

The bamboo clump density at these sites ranged from 230 to 260 clump ha^{-1}. The average number of culms per clump at the commencement of the study was 4 (supporting culms only) at the harvested site relative to 55 at mature site. The number of culms in each clump varied between 20 and 100 at mature site. Culm diameter and height varied from 0.5 cm to 5 cm and 1.5 m to 9 m, respectively. The other woody associates were: *Ziziphus glaberrima* (Sedgw.) Santapau., *Z. oenoplia* (L.) Mill., *Acacia catechu* (L.f.) Wild., *Ventilago caliculata* Tulsane and *Lagerstroemia parviflora* Roxb. The herbaceous layer was well developed during the rainy seasons (density, 403-487 shoots m^{-2}). *Heteropogon contortus* (L.) Beauv. ex. Roem. and Schult., *Rungia repens* (L.) Nees., *Cassia pumila* Lamk., and *Borreria hispida* (L.) K. Schum. were the dominant herbs (Tripathi and Singh. 1994).

Dry matter and nutrient measurements

The aboveground biomass of bamboo and other woody species was determined with the help of regressions relating diameter or girth with biomass (Tripathi and Singh, 1994). The herbaceous aboveground biomass was harvested every month from ten 50 cm x 50 cm plots and dried at 80°C. The rhizome biomass was estimated by excavating 5 clumps at each site. Fine root biomass at each site was estimated periodically at three distances (50, 150 and 250 cm) from the bamboo clump base. At each site 15 soil monoliths (each 15 x 15 cm, 60 cm deep) were excavated every time and washed over a sieve system. Root biomass was separated into bamboo roots, other woody species roots and herb roots (including rhizome). Roots were further separated into live and dead categories. For root in-growth observation, in the beginning of every season, 15 pits (each 15 x 15 cm, 30 cm deep) were dug at above distances. All the root materials were recovered from the soil originating from the pit. Galvanized iron wire cages (having 1 cm^2 pores) were fitted along the walls of the pits. All pits were refilled with own root-free soil. These cages were removed at the end of the season and the ingrown roots were recovered, washed and dried.

Net aboveground production of bamboo and other woody species were estimated through allometric equations using diameter and girth increments (Tripathi and Singh, 1994). The aboveground production was derived as the sum of leaf production, non-leaf litterfall, and biomass increment in different components during the growing season. Aboveground net production of herbs was calculated by trough-peak analysis following Singh *et al.* (1979). Plant and litter samples were powdered and analysed in triplicate for nutrient concentration. Carbon and nitrogen concentrations were determined by Hereaus CHN-O-S Rapid Autoanalyser. Phosphorus was determined colorimetrcally and calcium, potassium and sodium with a flame photometer (Allen *et al.*, 1986).

The dry matter values for standing crop biomass, net production, litterfall and root mortality were converted to C equivalent. The gross uptake of nutrients was calculated (separately for bamboo, other woody species and herbs) as the product of net production of different components and their respective nutrient concentrations. The net uptake was calculated after correction for nutrient withdrawal by comparing nutrient/C ratios in green and senescing leaves. The nutrient concentration in litterfall and fine roots were multiplied by the weight of annual litterfall and root mortality to compute the amounts of nutrients transferred to the soil.

RESULTS AND DISCUSSION

Considerable seasonal variations occurred in the amount of fine root biomass (Fig 1). Amounts of live roots were maximum (593-631 g m^{-2} m) during the rainy season and

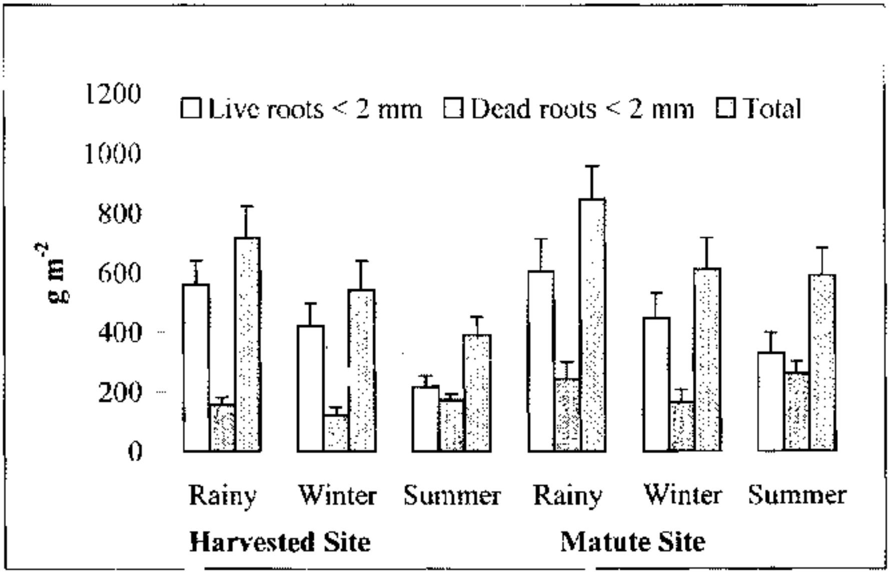

Figure 1. Seasonal changes in the amount of different fine root categories (60 cm depth) in two bamboo ecosystems from June 1987 to May 1989. Values are means ± SE.

minimum (231-341 g m^{-2}) during the summer. The bulk of fine root biomass (80-85%) belonged to the < 1 mm diameter size. Through the annual cycle, the proportion of dead fine roots was maximum (40-42% of live+dead) in the summer and the minimum (21-28%) in rainy season. This indicates substantial fine root mortality during summer and rapid disappearance of accumulated dead roots during rainy season. Root biomass increments in the present study showed that the bulk of fine root production (85-90%) occurred in the rainy season and the rest during the winter. Root in growth cages showed that of the annual total fine root production, 64-70 per cent occurred in the rainy season, 26-30 per cent in winter season and 4-6 per cent in summer season. This suggests that the fine root productivity in dry tropical bamboo ecosystem is strongly influenced by alternating wet and dry conditions of the region. Rainfall and temperature are the major variable responsible for temporal changes in fine root dynamics (Singh *et al*., 1984).

The live shoot biomass varied between 0.5 and 109 g m^{-2} at the harvested site and between 0.3 and 104 g m^{-2} at the mature site (Fig. 2). The first shower of monsoon rain triggered the growth of herbaceous vegetation. Most of the growth was completed during the rainy season (July-October) and the peak biomass was attained in the mid of rainy season. The herbaceous plant biomass decreased during the dry season as the biomass of live shoots was drastically reduced. The live shoot mass peaked in August and decreased in the following period, reaching lowest value in May. The standing dead shoot mass ranged from 3.6-45 g m^{-2} at the harvested site and 0.5-48 g m^{-2} at mature site (Fig. 2). Dead shoot mass was highest in November-December. The minimum dead shoot mass occurred in July at both the sites.

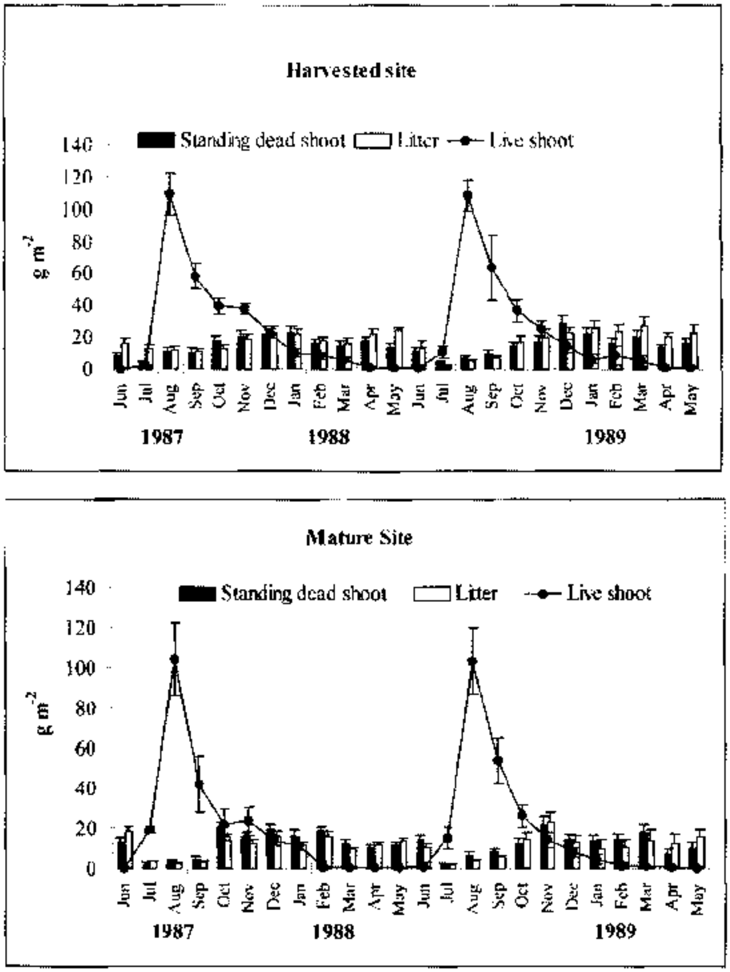

Figure 2. Monthly variations in the amount of different herbaceous components (*i.e.* live shoot, standing dead and litter) on two bamboo ecosystems from June 1987 to May 1989. Values are means ± SE.

During the two annual cycles, herb litter mass ranged from 3-21 g m^{-2} and 4-24g m^{-2} at the harvested and mature sites, respectively (Fig. 2). Herb litter mass broadly followed the standing dead shoot mass dynamics. Both increased during the summer season (March-May) and decreased during the rainy season (July-October) due to the simultaneous conversion of live shoots in the standing dead and further in litter categories during summer.

Litter decomposes through three processes *viz.*, leaching, comminution and catabolism which may be temporarily separated or superimposed (Swift *et al.*, 1979). Marked temporal variation occurred in the amount of different litter categories. The highest share of fresh litter was found in the summer months, while the partly decayed and particulate litter showed the maximum contribution in the wet months. This reflected the simultaneous process of conversion of fresh litters into partly decayed and further into particulate as a result of abiotic and biochemical changes occurred in litter during the course of time. The particulate litter acts as a site for microbial activity and thus, work as a sink (through immobilization) and source (through mineralization) of various nutrients. Strong immobilization of N and P was apparent in the litter mass in the bamboo savanna, which was indicated by higher concentrations of these nutrients in the partly decayed and particulate litter mass compared to fresh litter (Tripathi and Singh, 1995).

Moreover, nutrient concentrations change considerably in different litter categories. Marked reduction of nutrient concentrations in herbaceous live shoot and bamboo leaf (active component) during senescence indicated retranslocation of large fraction of leaf nutrients (58-68% N, P and K) to the permanent organs (passive components). Movements of nutrient from the dying roots into surviving roots and rhizome were also suggested by greater nutrient concentration in live root compared to the dead ones (Tripathi *et al.*, 1999). High nutrient retranslocation in the active components of bamboo savanna is likely to be related to the low fertility of the site, probably a limitation of N and P available to support the plant growth.

The fine roots add considerable amount of organic matter (55-65% of the total above- and below ground return) and different nutrients (30-66%) annually to the soil. In a variety of forests, contribution of fine roots to the total organic matter input to the forest floor was 20-77 per cent (Vogt *et al.*, 1986). It is important to note that the bamboo fine roots constitutes as much important pathway of organic matter deposition in soil as its leaf litter. The high turnover of bamboo roots probably contributes significantly to the continual regeneration of nutrients (N and P) which supports high net production of bamboo in a basically oligotrophic soil system (Tripathi and Singh, 1994). Greater addition of nutrients to the soil by fine roots than litterfall in the bamboo savanna may also serve as a premium against N and P losses due to fire and rains.

Total standing crop biomass in the bamboo savanna was 47.3 t ha^{-1} at mature site (Table 1). Bamboo harvest reduced the stand biomass to 35 t ha^{-1}. The dry matter storage in the active components (leaf, herb and fine roots) was only 24-27 per cent compared to 73-76 per cent in the passive (stem, branch, rhizome and coarse root) components at these sites. In the harvested site, two-third of the total storage in active components was contributed by fine roots, however, in the mature site fine root and leaves contributed almost equally. Contribution of the herbs to the total active component was only 3-5 per cent. In contrast to the biomass distribution, of the total dry matter production, the active components accounted for 70-80 per cent of total compared to only 20-30 per cent in passive components.

Carbon varied in different components. The mean concentrations were: bamboo leaf (37%), wood (44%), rhizome (42.5%), roots (40.5%) other woody species leaf (43.3%),

Table 1. Total dry matter (DM) and nutrients and their per cent contribution in different components and major fluxes in harvested and mature bamboo savanna sites

	Harvested site					Mature site				
	Total	L (%)	W (%)	CR/R (%)	FR (%)	Total	L (%)	W (%)	CR/R (%)	FR (%)
Biomass (t ha^{-1} ± SE) and nutrient stock (kg ha^{-1} ± SE)										
DM	35±5	7	55	21	17	47.3±8	12	60	13	15
N	301±42	17	43	22	18	412±51	28	44	13	15
P	16±2	18	52	17	13	23±3	26	47	15	12
Ca	285±38	10	60	20	10	339±44	26	53	11	10
K	170±22	18	50	18	14	268±36	37	45	10	8
Na	13±2	16	52	19	13	18±2	20	62	8	10
Production (t ha^{-1} yr^{-1} ± SE) and nutrient uptake (kg ha^{-1} yr^{-1} ± SE)										
DM	15.8±3.3	22	24	6	48	19.3±3.7	36	17	3	44
N	176±28	23	17	7	53	184±37	32	15	4	49
P	7±1	24	26	5	45	9±1	36	20	3	41
Ca	119±24	36	27	5	32	169±28	57	16	2	25
K	82±15	27	27	5	42	93±27	45	20	4	31
Na	5±1	28	25	5	42	6±1	37	22	2	39
Return(t ha^{-1} yr^{-1} ± SE for dry matter and kg ha^{-1} yr^{-1} ± SE for nutrients)										
DM	11.6±2.7	25	10	-	65	15.9±3.2	37	8	-	55
N	143±32	27	7	-	66	154±35	33	7	-	60
P	5±1	30	10	-	60	7±1	40	8	-	52
Ca	86±18	48	9	-	43	141±22	62	8	-	30
K	58±15	37	6	-	57	72±12	54	7	-	39
Na	4±1	35	14	-	51	5±1	47	11	-	42

L = woody species leaf + herbs, W = wood, CR/R = coarse root + rhizomes and FR = fine roots.

wood (41.7%), coarse root (40.2%), fine root (45.6%) herbs aboveground (34.3%) and belowground (35.0%). The dry matter values for standing crop biomass, net production, litterfall and root mortality were converted to C equivalent (*i.e.* the product of C concentration and dry mass). The total quantities of C in the system were: 74.5 t ha^{-1} at mature site and 64.4 t ha^{-1} at harvested site, distributed 23-28 per cent in vegetation, 1.7-1.8 per cent in litter, and 70-75 per cent in soil. Aboveground storage was 76 per cent of the total vegetation C in mature site and 68 per cent in harvested site. The total soil C storage was 53.3 t ha^{-1} at mature site, however, it decreased to 48.1 t ha^{-1} at harvested site. The values of C storage in the present study fits at the lower end of the range reported for soil C storage in the dry tropical forests (45-113 t ha^{-1}, Singh, 1989 b; Brown and Lugo, 1982).

Annual C addition to the soil through fine root mortality and litter decomposition range from 2.5-2.6 t ha^{-1} and 1.1-1.8 t ha^{-1}, respectively, at these sites. Despite significant decrease in aboveground C stock in harvested site, the addition of C through fine root mortality was comparable at both the sites. However. a decrease in the amount of total C added to soil was observed at harvested site, mainly because of decreased litter input at this site. Substantial amounts (3.6-4.4 t ha^{-1} $year^{-1}$) of C were transferred from the active component of vegetation to the soil compared to total net fixation (production) of 6.3-8.7 t ha^{-1} $year^{-1}$.

Similarly. the nutrient stocks in active components were also low (20-35% of the total at harvested site and 30-44% at mature site). This can be compared with their contribution in the total nutrient uptake (65-80% at harvested site and 55-70 % at mature site). Fine roots accounted for more than half of the nutrient (except Ca) uptake by the active components at both sites. The share of active components to the total nutrient return was 86-94 per cent; the contribution of fine roots was greater than those by leaves and herbs (Table 1).

The total net production in the bamboo savanna was estimated to be 15.8 t ha^{-1} yr^{-1} in the harvested site and 19.3 t ha^{-1} yr^{-1} in the mature site (Table 1). The bamboo savanna net production ranked towards the upper end of the range (5-19 t ha^{-1} yr^{-1}) obtained in the natural forests (Singh, 1989 a, b). Bamboo savanna maintains such a high level of net production despite lower nutrient availability in soil (Singh *et al.*, 1989) and lower level of plant biomass and nutrient stocks (Singh, 1989 b) relative to the natural forest. The root/shoot production ratio in the bamboo savanna was considerably higher relative to the ratio in the nearby natural forest (Singh and Singh, 1991). The harvesting of bamboo resulted in greater annual allocation (83%) of dry matter to the belowground parts, which led to the development of an extensive root system, capable of absorbing substantial amounts of water and nutrients from the soil, where these are essentially limited. It is suggested that under prevailing strong biotic and abiotic stresses, bamboo harvesting tends to accelerate accumulation of a larger fraction of production belowground for maintaining production efficiency.

The dry matter and nutrient stocks in active components were low (24-44% of the total) compared to 55-76 per cent in passive components at bamboo savanna sites (Table 1). Thus, it is important to mention that quite disproportionate to their structural role (*i.e.*, relative storage), the active components play a more crucial role in the functioning (relative contribution in nutrient cycling) of bamboo savanna for maintaining the production efficiency of these ecosystems despite substantial nutrient export (N and P) from the system. Moreover, several nutrient conservation mechanism *viz.*, nutrient withdrawal, nutrient use efficiency and nutrient immobilization, all geared toward better utilization of meager resources (low nutrient availability in soil), are occurring in active components of bamboo savanna ecosystem. These mechanisms may efficiently contribute towards high resilience of bamboo savanna against anthropogenic pressure such as grazing, and periodical harvesting, *etc.* Active components show marked seasonality and contributed substantially (86-94%) to the total dry matter and nutrient additions in the soil.

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