NUTRIENT DYNAMICS OF A LOWER SIWALIK BAMBOO FOREST IN THE GARHWAL HIMALAYA, INDIA.

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JOSHI, A.P., SUNDRIYAL, R.C. & BALUNI, D.C. 1991. Nutrient dynamics of a lower Siwalik Bamboo Forest in the Garhwal Himalaya, India. Nutrient dynamics of N, P and K were studied for a bamboo forest in the Garhwal Siwalik Himalaya, India. Bamboo culms are felled once in every fourth year and this felling cycle is continued to last one century. Most of the culms of bamboo had attained an age of 2 to 4 *y* in the forest studied. The relative contribution of various components to the standing state of biomass is in the order: bamboo culms > branches > leaves > herbs. Nutrient concentrations were higher in leaves than any other plant components. Among nutrients K showed the highest concentration, followed by N and then by P. About 63, 16 and 73 $kg\,ha^{-1}$ of N, P and K, respectively was recorded in standing biomass, out of which 5, 1 and 2 $kg\,ha^{-1}$ of the respective element was returned to the soil. Lower standing state of nutrients, lower uptake and return in the studied forest can be attributed to lower age of bamboo culms, and to existing management practices. It was concluded that removal of bamboo culms in every four years for commercial purpose impoverished the soil nutrient status and thus the fertility of soil is poor under bamboo in the Garhwal Siwalik Himalaya.

Key words: Nutrient dynamics - *Dendrocalamus strictus* - Siwalik Garhwal Himalaya - nitrogen - phosphorus - potassium

Introduction

Bamboos are perennial woody grasses and have world wide distribution. Numerous reports are available on bamboos particularly with respect to their distribution, uses, growth behaviour, anatomy and cytology, and production (Raizada & Chatterjee 1956, Varmah & Bahadur 1980, Tiwari 1981). Bamboo besides its various traditional uses is commonly used in afforestation due to its fast growth, easy propagation and soil binding properties. The bamboo species *Dendrocalamus strictus* forms a dominant middle storey crop of sub-tropical forests of the Garhwal Himalaya. Reports indicate that this species has a flowering cycle that varies between 20 to 60 *y* (Clement 1956, Wang & Chen 1971, Gaur 1985), while a single culm has an age of about 9 to 12 *y* (Sharma & Tomar 1963).

Nutrient status of some Himalayan and other forests have been estimated by Duvigneaud and Denaeyer De-Smet (1970), Johnson & Risser (1974), Pandey and Singh (1981), Toky and Ramakrishnan (1982, 1983), Negi *et al.* (1983), Chaturvedi and Singh (1987), and Rawat and Singh (1988). However, there is little knowledge on the functional role of bamboo species in tropical humid forests (Numata 1965, 1970, Janzen 1976, Rao & Ramakrishnan 1989). There is a need to extend such studies in other bamboo forests as well. In consideration of this, the present project was conducted to study the nutrient dynamics of *D. strictus* in the lower Siwalik forest at the foot hills of the Garhwal Himalaya.

Study area and characteristics of bamboo stands

The study area comprising bamboo (*D. strictus*) forest is located near Kotdwara town in the bhabar tract of lower Siwalik Himalayan ranges of district Pauri Garhwal (lat. 29°46' N, longtd. 78°30' E, elevation 395-475 *m*) (Figure 1). The whole Garhwal region is a rugged mountainous terrain with a very narrow strip of bhabar marking the southern boundary of the region. Siwalik ranges form the southern range of the Himalayan system and separate the Himalaya proper from the Indo-Gangetic plain of north India. Siwalik ranges and bhabar tract have a height of 325 to 1200 *m* above sea level. The general topography of the study area is gently undulating. The soils are alluvial and covered with tertiary sandstones, soft earthy deposits, gravel, conglomerates, shales and mud stones.

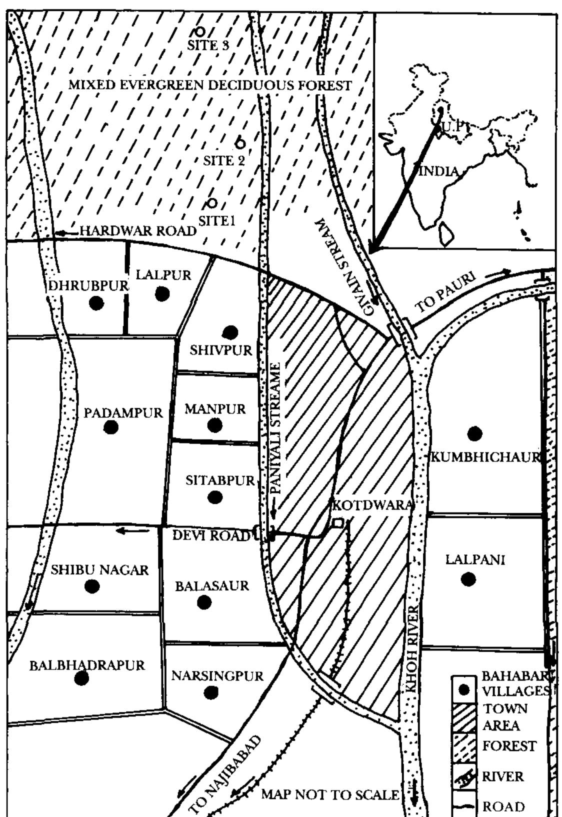

Figure 1. Location map of the study sites in the mixed evergreen-deciduous Siwalik forest; Kotdwara township area; and bhabar villages in the Garhwal Himalaya, all bhabar villages are dependent on the forest for fuel, fodder, timber and other commercial purposes

The climate of the study area is characterised by a summer monsoon and the year can be divided into three seasons, such as summer (March-June), rainy (July-October), and winter (November-February). The annual rainfall (from June 84 to May 85) in the area was 1540 *mm*, most of which was recorded in the rainy season. Mean maximum and minimum annual temperatures recorded were 29°*C* and 15°*C*, respectively. Lowest temperature was recorded in January, while the highest temperature in June (Figure 2).

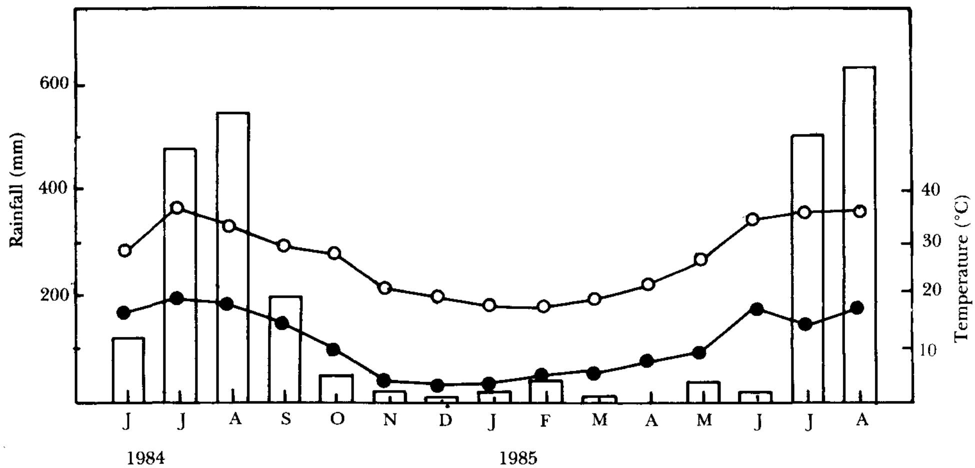

Figure 2. Rain fall (bars), maximum temperature (hollow circles) and minimum temperature (solid circles) data for the study area during 1984 and 1985

The lower Siwalik Himalaya has three major forest types, such as mixed dry deciduous, dry Siwalik sal and moist Siwalik sal forests (Champion & Seth 1968). The important tree species are *Shorea robusta, Terminalia tomentosa, Lagerstroemia parviflora, Mallotus philippensis, Buchnania langen, Anogeissus latifolia, Albizia lebbeck* and *Emblica officinalis* (Joshi & Gupta 1984). Alluvial deposits are dominated with *Acacia catechu, Dalbergia sissoo, Aegle marmelos* and *Holoptelea integrifolia* (Joshi 1984). Bamboo forms a major middle storey throughout these forests and is found growing with 45 other tree species (Joshi & Purohit 1983). At certain locations bamboo forms pure stands. On the whole, all the forests give mixed evergreen deciduous appearance throughout the year.

For the nutrient study, we selected three stands (sites) of bamboo (Figure 1). The forest floor has a few herbs but no shrub. Density of bamboo was estimated as 360, 285 and 257 clumps *ha*$^{-1}$ at sites 1 to 3, respectively, which can be considered as well developed and dense stands (Joshi 1984, Gaur 1985). At all three sites each bamboo clump had 22 and ten, 15 and eight, and, 14 and six old and new culms, respectively. However, on average basis one clump had about 17 old and eight new culms. Forest records indicated that most of the old culms had attained an age of 2 to 4 *y*. The bamboo species *D. strictus* covers about 62, 49 and 53% ground cover at the three sites, respectively. Herbaceous vegetation was relatively higher at site 3. All bhabar villages use the studied forest for fuel, fodder and other commercial purposes.

Biotic pressure

All Siwalik forests, particularly in Garhwal Himalaya, are under intense biotic pressure. A huge amount of wood and fodder is collected each year by nearby inhabitants. In addition, grazing is common by both domestic as well as wild animals.

Due to its diverse uses bamboo culms are felled once in every four years by the Forest Department. Forest records show that this felling has continued since 1882. Before 1976, this felling was done by forest contractors, and due to illicit felling most of the bamboo areas were denuded. Since 1976, the Forest Department has been supervising the felling under certain rules: the culms less than one year of age are prohibited from felling, and in each clump at least five culms should remain intact. The height of cutting should be 15 to 30 *cm* above soil surface and at least one node should be left during cutting. The periodic cutting is done (with sharp knives and axes) between November to March once in every fourth year. However, in many instances, violation of these rules is evident. Bamboo leaves are used as fodder by wild animals, particularly the elephants, and due to abundance of those animals in the forest, damage is significant. Newly emerging shoots are also removed by local inhabitants as food. About 60% of the total new buds were recorded removed in the study area.

Methods

Nutrient and biomass pools

Soil nutrient analysis was done at the beginning of the study (June) at each site. Soil samples (n=10) were collected from two stratum (0-10 and 11-30 *cm*) and air dried. These samples were mixed, homogenized and sub-samples were stored awaiting chemical analysis.

As new culms of bamboo first start sprouting in the last week of July, first harvesting was done in August. All biomass sampling occurred between August 1984 to August 1985. Ten clumps of bamboo comprising old and new culms, branches and leaves were demarcated at each site for biomass analysis. Up to twelve old and new culms of bamboo varying in different diameter classes and heights were harvested each month. Instead of harvesting all ten clumps at one time, we used the monthly harvesting method by selecting bamboo culms of different diameters. This method has decided advantage over the single harvest method because it expresses changes (particularly at the time of active growth between August to December) in new and old culms, and leaves of bamboo throughout the year. Besides, the method is less labour intensive and save a considerable biomass at the end (*e.g.* if we remove 10 clumps having 25 culms each, then 10 × 25 = 250 culms were to be harvested; but here we selected 12 culms at random and harvesting was done for 13 months, then only 12 × 13 = 156 culms were removed, a net save of 250 - 156 = 94 culms at each site).

The average biomass values of each new and old culms were multiplied with the total number of respective culms per clump, to get the biomass value in terms of $clump^{-1}$ basis. Further, the average biomass value of each clump was multiplied with mean density, to get the biomass value in terms of ha^{-1} basis. Root samples were collected (up to a depth of 30 *cm*) for estimating nutrient concentration only. No biomass data were recorded for root due to inaccuracies and practical difficulties.

The herbaceous vegetation of the forest floor was also harvested each month using a sampling unit of 50 × 50 *cm* size. The samples were separated into above ground and below ground parts. Litter samples were collected from different 1 × 1 *m* litter traps at each site in every month. The net primary productivity for different bamboo components, herbs and litter biomass was measured by summing positive increments in the respective standing crop during the sampling intervals. All the samples were oven dried at 60°*C* for 36 *h*.

For each bamboo component, replicate (3-5) samples of each new and old culms, branches, and leaves were taken, ground to pass 1 *mm* sieve and stored for chemical analysis. Samples of herbaceous vegetation separated into above ground and below ground parts were also ground and stored. Similarly, litter samples were ground to powder for nutrient analysis.

Nutrient quantities in the bamboo were obtained by multiplying the total biomass of each component of bamboo by the average nutrient concentration in that component. The nutrient content of herbaceous vegetation and litter was determined by multiplying their biomass with respective nutrient concentrations. To minimise errors in nutrient content, the biomass of bamboo culms, branches and leaves, herbaceous vegetation, and litter from different sites were pooled together for each component, taking care to include each component in the same proportion as they occurred at different sites, and thus the nutrient dynamics for an average Siwalik Himalayan bamboo forest is presented.

Nutrient uptake was computed by multiplying the value of net primary productivity of different components of bamboo with their respective nutrient concentration. The values of nutrient uptake by bamboo and herbs were summed to estimate the total annual uptake by the forest. The annual turnover of each element was calculated by dividing the quantity which left a given ecosystem compartment by the quantity held in that compartment (Reiners & Reiners 1970).

Chemical analysis

Sub-samples of soil were taken for estimation of total nitrogen, available phosphorus and exchangeable potassium (Jackson 1958). The contents of the N, P and K in oven dried ground plant samples (n=3 to 5) were analysed. Nitrogen was determined by the micro-Kjeldahl method. Phosphorus was estimated from a wet ash solution, while flame photometer was used for estimation of potassium (Allen *et al.* 1974).

Results and discussion

Biomass

Biomass distribution of bamboo species *D. strictus*, herbaceous vegetation and litter at the sites are presented in Figures 3 to 5. It can be seen that the three sites have a similar pattern of biomass accumulation in different months; however, this biomass was partitioned in slightly different way in each of the site. The growth rate of new culms was very high (up to 52 to 55 *g* culm^{-1} day^{-1}) until November to December. Old culms, however, showed a slow rate of biomass accumulation. Agrawal and Gupta (1987) have reported an average of 59 *g* culm^{-1} day^{-1} biomass accumulation for *D. strictus* in the same forest. Comparing bamboo biomass at the three sites (Figure 3), it can be seen that site 1 had the highest proportion of biomass in different components *viz* old culm, new culm and leaves, while, site 3 had the least. The respective proportion of old culm, new culm and leaves was nearly equal at each site and amounted to 72, 21 and 7% at sites 1 and 2, and 70, 23 and 7% respectively at site 3 (Table 1). The biomass values of this investigation are lower than those recorded for other bamboo forests (Seth *et al.* 1963, Rao & Ramakrishnan 1989). It can be attributed to the lower age of bamboo culms and existing management practices in this forest. Annual net primary production amounted to 3117, 2329 and 2382 *kg ha*$^{-1}$ for leaves at sites 1 to 3, respectively. The average production of bamboo new culm, old culm and leaves across all the sites amounted to 2609±440, 664±136 and 665±107 *kg ha*$^{-1}$ respectively.

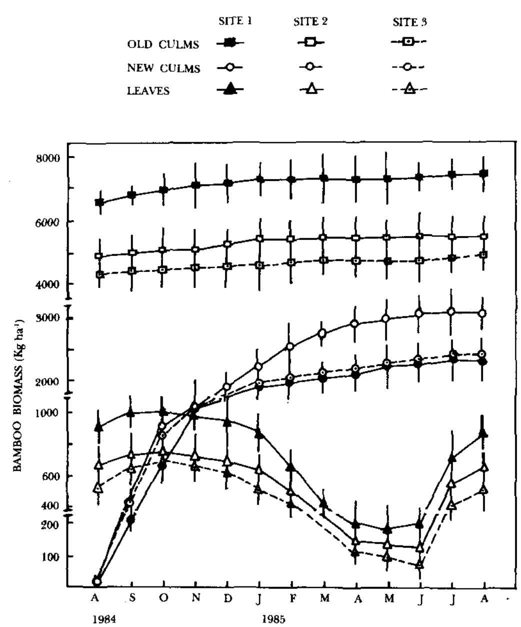

Figure 3. Changes with time in the biomass of bamboo components in the Garhwal Siwalik Himalaya (Vertical bars represent ± 1 SD)

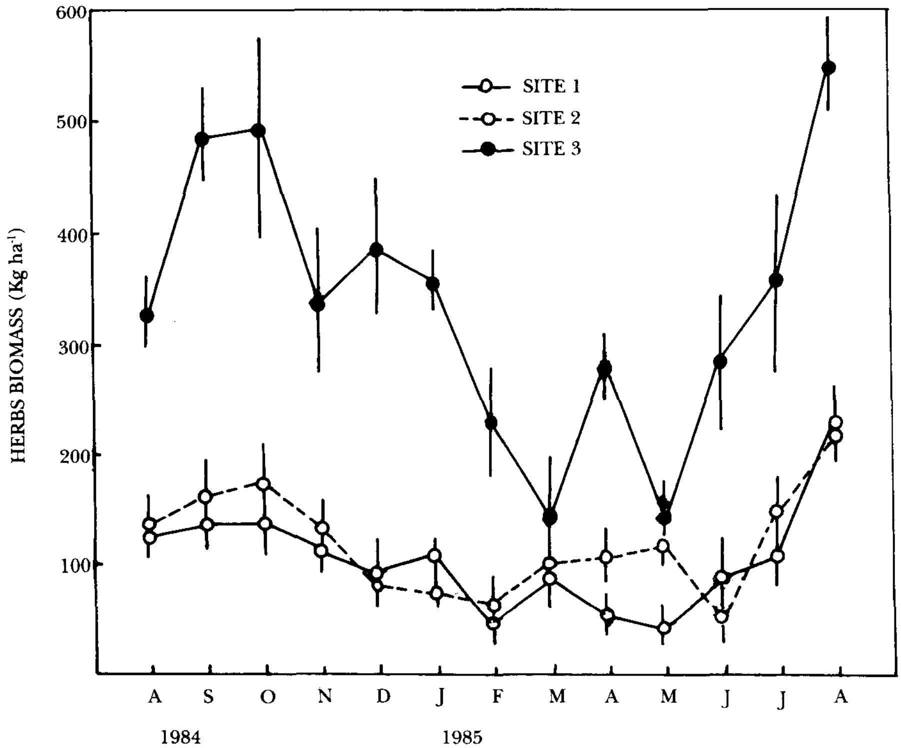

Figure 4. Monthly variation in the above ground biomass of herbs on the forest floor of bamboo from August 1984 to 1985 (Vertical bars represent ±_1 SD)

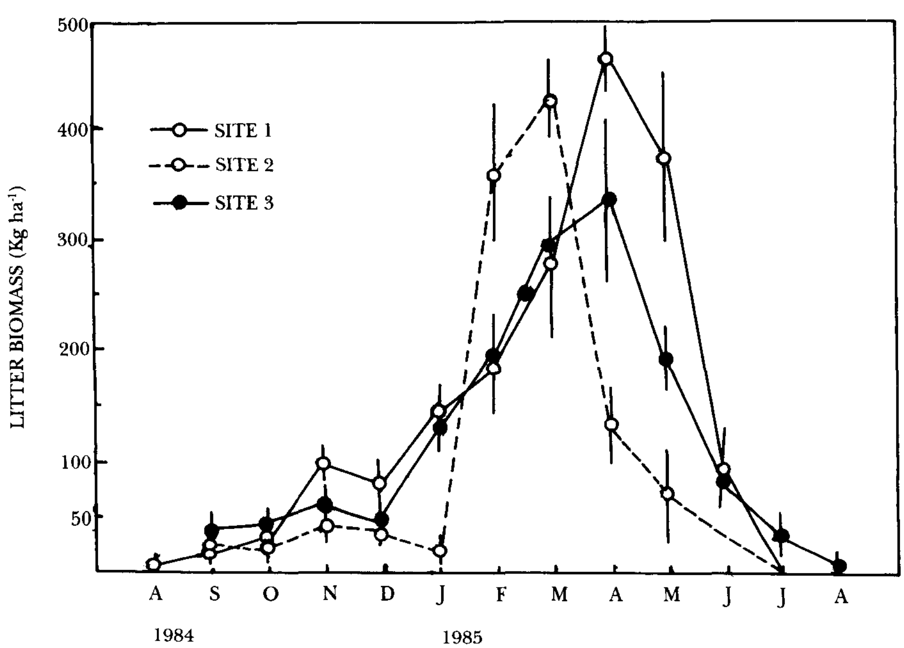

Figure 5. Monthly variation in litter biomass on the bamboo forest floor (Vertical bars represent ± 1 SD)

Table 1. Aboveground biomass of *Dendrocalamus strictus* and herbs at different site in the bamboo forest (mean ± 95% confidence interval)

Site	*Dendrocalamus strictus*						Herbs (*kg ha*$^{-1}$)	Total (*kg ha*$^{-1}$)
	kg clump^{-1}			*kg ha*$^{-1}$				
	New culm	Old culm	Leaves	New culm	Old culm	Leaves		
I	5.84±0.50	20.22±1.41	1.95±0.30	2102±192	7279±403	702±80	109±29	10192±806
II	5.51±0.46	19.09±1.84	1.84±0.23	1570±135	5441±344	524±66	122±31	7657±642
III	6.12±0.38	18.36±1.03	1.72±0.25	1573±100	4719±267	442±54	338±58	7072±652

Site 3 had the greatest proportion of herbaceous vegetation (Figure 4), the total weight being 3.1 and 2.8 times greater than sites 1 and 2, respectively (Table 1). Lower density and biomass of bamboo at site 3 perhaps allowed herbaceous vegetation to grow at this site. Our results are in agreement with those of Rao and Ramakrishnan (1989), who reported that with the increase in bamboo biomass, the herbs biomass decreased. In this study the contribution of herbaceous biomass to total biomass was relatively smaller than that of bamboo ($P < 0.001$), which contributed only about 1% at sites 1 and 2 and 5% at site 3 (Table 1). Annual herb production amounted to 215, 283 and 756 *kg ha*$^{-1}$ at sites 1 to 3, respectively.

Monthly variation in the litter biomass at the three sites is presented in Figure 5. The highest values were recorded in March and April and the minimum in August. These fluctuations reflect the monthly variation in leaf fall of bamboo and herbaceous vegetation. During March to June the rate of leaf fall of bamboo was very high which may cause death of ground vegetation and thus increase the biomass in litter compartment. Total annual litter production for sites 1 to 3 amounted to 583, 429 and 354 *kg ha*$^{-1}$, respectively.

Nutrient concentration

The percentage of minerals varied in the different components of bamboo and herbs (Table 2). The concentrations of N, P and K were lower in culm than leaves of bamboo and above ground parts of herbs. The concentration of nitrogen was higher in bamboo leaves than those of phosphorus and potassium. However, in the culm, the order of nutrient according to concentration was K>N>P. Similar trends have also been reported for different bamboo species by Seth *et al.* (1963), and Rao and Ramakrishnan (1989). Pai-hui (1985), however, reported the trend of elements in a bamboo species *Phyllostachys pubescens* as N>K>P.

The concentration of the three nutrients in *D. strictus* components ranged between 0.47 to 2.27, 0.11 to 0.39 and 0.41 to 1.92% for N, P and K, respectively (Table 2). Seth *et al.* (1963) reported 0.21 to 1.0, 0.15 to 0.28 and 0.42 to 1.99% of the respective elements in the same species at New Forest, Dehra Dun. The values of N, P and K ranged between 0.16 to 2.47, 0.03 to 0.20 and 0.18 to 1.81, respectively in *P. pubescens* (Pai-hui 1985). In *Dendrocalamus hamiltonii* the concentration of the same nutrients varied from 0.44 to 3.20, 0.15 to 0.47 and 2.0 to 3.1, respectively (Rao & Ramakrishnan 1989). In all these reports, however, the concentration of nutrients was higher in leaves and it decreased in stem parts. The concentration of nutrients was highest in new leaves and decreased in older leaves. Similarly, new culm had higher nutrient concentration than old culm. This can be attributed to leaching by rain and/ or translocation of the elements. Similar reports have been published by Pai-hui (1985) and Youdi *et al.* (1985). The nutrient concentrations were also higher in new shoot but decreased with the increase in age. Chaozong (1985) also reported higher amount of nutrients in new shoots. With the exception of bamboo leaves, the herbaceous vegetation had higher nutrient percentage. Chaturvedi and Singh (1987) and, Rawat and Singh (1988) while studying pine and oak forests, respectively, reported that the concentration of nutrients in different life forms was in the order: herbs > shrubs > trees. The order of the three elements as percentage concentration in 0 to 30 *cm* soil depth was C>N>K>P (Table 3). The percentage of carbon was eight times more than that of nitrogen, 130 times more than that of phosphorus and three times more than that of potassium. Nitrogen concentration was about 15 times more than that of phosphorus and three times than that of potassium. The level of nutrients in a given soil is the net outcome of input and output from the system. Nutrients from the plants return to the soil through litter fall. Thus surface soil shows a relatively higher proportion of nutrients (Table 3).

Table 2. Mean percentage content of nutrient in the bamboo components and herbaceous vegetation (means ± S.D.)

Plant components	N	P	K
Dendrocalamus strictus:			
New culm	0.72±0.20	0.16±0.07	0.96±0.25
Old culm	0.59±0.17	0.18±0.06	0.73±0.08
Branch	0.91±0.13	0.19±0.03	0.98±0.36
Leaf	2.27±0.51	0.39±0.01	1.92±0.33
Rhizome	0.47±0.11	0.11±0.03	0.41±0.10
Herbs:			
Above ground	1.88±0.28	0.49±0.11	1.71±0.12
Root	1.01±0.14	0.08±0.04	0.43±0.15
Litter	1.19±0.19	0.24±0.05	0.51±0.13

Table 3. Concentration (% ±SD) and content (*kg* ha^{-1}) of nutrients in the soil up to a depth of 30 *cm*

Depth (*cm*)	Organic carbon	Total Nitrogen	Available Phosphorus	Exchangeable Potassium
Concentration (%):				
0-10	2.10+0.14	0.25±0.03	0.016±0.002	0.110±0.05
11-30	1.52+0.13	0.19±0.06	0.007±0.002	0.069±0.01
Content (*kg* ha^{-1}):				
0-10	17216	3158	61	202
11-30	10092	2093	45	124
Total	27308	5251	106	326

Standing capital/pool of nutrients and release

The distribution of nutrients in different components of bamboo species varies considerably due to variation in biomass and nutrient concentration. The standing crop of nutrients in different plant components varied with their biomass. Large amounts of nutrients were recorded in old and new culms, although leaves and branch had comparatively higher concentration of nutrients (Table 2). The relative contribution to this standing state was in the order : stems > branch > leaves > herbs. Similar trends in nutrient content among plant components in different forests were published by Johnson and Risser (1974), Feller (1980), Chaturvedi and Singh (1987) and Rawat and Singh (1988). In this investigation, maximum above ground pool of N, P and K was 96, 24 and 110 *kg* ha^{-1} respectively, with an average of 63, 16 and 73 *kg* ha^{-1} for the respective element (Table 4). Rao and Ramakrishnan (1989) reported 75, 31 and 281 *kg* ha^{-1} of N, P and K respectively in a 5-*y*-old bamboo stand, and it increased with stand age. Seth *et al.* (1967) recorded 597, 680 and 1220 *kg* ha^{-1} of N, P and K respectively in aboveground biomass of a 15-*y*-old bamboo forest. These reports indicated that the quantity of standing nutrients increases with bamboo age. In the present study, net annual uptake of N, P and K, based on net annual productivity, was 46, 9 and 50 *kg* ha^{-1} respectively (Table 4). It shows that K is taken up in the highest quantity, followed by N and P. Our results are in agreement with those of Seth *et al.* (1963) and Rao and Ramakrishnan (1989). Baluni (1989), however, reported the uptake trend as N>K>P.

Table 4. Nutrient content in the bamboo, herbs and total vegetation, annual uptake (in parenthesis), and return through litter in the bamboo forest of the Garhwal Siwalik Himalaya

Nutrient	Aboveground biomass (Uptake) Bamboo (*kg* ha^{-1})	Herbs (*kg* ha^{-1})	Total (*kg* ha^{-1})	Total return through litter (*kg* ha^{-1})	Returning content as % of standing content (turnover)
Nitrogen	59.5±12.5 (37.8±6.4)	3.6±0.6 (7.8±5.5)	63.1±8.4 (45.6±5.0)	5.4±1.4	8.6
Phosphorus	15.4±4.6 (7.3±1.2)	1.0±0.3 (2.0±1.4)	16.4±3.0 (9.3±1.9)	1.1±0.3	6.7
Potassium	69.8±16.8 (42.7±7.3)	3.3±0.8 (7.2±5.0)	73.1±14.1 (49.9±9.6)	2.3±0.6	3.1

Litter fall from the forest to the floor is normally considered as the main way for nutrient return to the soil. Total return of the nutrients in this study was about 5.4, 1.1 and 2.3 *kg* ha^{-1} y^{-1} for N, P and K, respectively (Table 4). They represent about 9, 7 and 3% of the respective uptake from the soil. Seth *et al.* (1963) revealed that only 5.37, 0.71 and 1.42% standing content of N, P and K, respectively, were released to the soil in *D. strictus* forest at Dehra Dun. Relatively higher nutrient release value were recorded for *D. hamiltonii* forest of north east India (Rao & Ramakrishnan 1989). Herbs contributed little to nutrient cycling in this bamboo forest. Lower amounts of nutrients returned can be attributed to the lower age of the bamboo culms. Element storage in the biomass and recycling through litter increased in older stands (Rao & Ramakrishnan 1989). Lower turnover for K was also reported and correlated with the rapid accumulation by dominant bamboo species *D. hamiltonii* (Toky & Ramakrishnan 1982, 1983) and slower release through litter fall. Relatively higher turnover of N and P can be attributed to their higher concentration in the leaves which is mainly responsible for turnover rates (Rao & Ramakrishnan 1989).

Conclusions

The reason that bamboo is found growing as a middle storey species commonly with few other species may be due to its shallow root, scant underground cover, low plant height and small canopy cover, and thus chances of competition with taller species for light, nutrition and space become low (Joshi & Purohit 1983). As all Siwalik forests are under severe biotic pressure, that is fuel, fodder and grazing by domestic cattle, migratory graziers and wild animals, its (bamboo) propagation through rhizome can be considered as an adaptation, which allows this grass tree to survive even under tremendous pressure. Bamboo culms are removed every fourth year and this felling cycle has continued for over one century in the Garhwal Siwalik Forests. Since bamboo grows rapidly during the rainy season, it absorbs a considerable amount of nutrients from the soil. If we compare nutrient requirement of a bamboo forest with other forests (Duvigneaud & Denaeyer De-Smet 1970, Thamdrup 1973, Van Cleve & Noonan 1975, Rawat & Singh 1988, Rao & Ramakrishnan 1989), only a small percentage of nutrients is brought into recirculation through the leaf fall. Repeated and illegal felling of bamboo removes a large proportion of the nutrients from the ecosystem. This can severely impoverish the soil and may account for the low fertility of the soil under bamboo in the Garhwal Siwalik Himalaya. Under such soils few other species can grow thus allowing the bamboo to dominate in pure stands. A longer felling cycle with better protective measures may improve the nutrient status of the soil under bamboo.

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