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Bioproduction and Nutrient Cycling in Seven Bamboo Species in Subtropical Indian Himalayas

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ABSTRACT

India is a home to a number of bamboo species, which are major woody components of many traditional Indian land use systems. Biomass production and nutrient cycling was studied in seven bamboo species in *viz.*, D*endrocalamus asper, Dendrocalamus hamiltonii, Bambusa ulda, Phyllostachys aurea, Dendrocalamus strictus, Melocanna baccifera, Phyllostachys bambusoides.* All the bamboo species showed significant difference with respect to growth performance. Higher values of growth parameters were recorded in *Dendrocalamus hamiltonii* (Diameter – 6.33 cm; Height – 9.35 meters) which was followed by *Dendrocalamus strictus* (Diameter – 6.06 cm; Height – 8.59 meters) and least values were found in *Phyllostachys aurea.* Below (2.41 Mg ha^{-1} $year^{-1}$) and above ground biomass carbon sequestration rate (4.57 Mg ha^{-1} $year^{-1}$), litter return (1.57 kg m^{-2}) and microbial biomass carbon (131.85 mg per 100 g of soil) was higher in *D. asper.*

Key Words:

Bamboo, Biomass, Carbon accumulation, Soil nutrient cycling, Himalaya.

INTRODUCTION

A bamboo is an important group of non-woody forest plants in tropical and subtropical regions of the world. Due to its high utility, which is closely interwoven with the life of the people, it is known as the “Poor man’s timber,” “Green gold of the forest,” and “Friend of the people.” More than 110 genera of bamboos reported with 1500 species all over the world (Subramaniam 1998). It is estimated that the bamboo stands occupy an area of 36 million hectares (ha) worldwide, which is equivalent to 3.2 percent of the total forest area. Over 80 percent of the total area covered by bamboo is located in Asia, 10 percent in Africa and America (Lobovikov et al. 2007). Bamboo covers 14 million hectares area of Indian forest (FSI 2011).

Bamboo has the potential to eradicate poverty, economic, and environmental development (FAO, 2005). Bamboos are common and vitalresources

that have multiple uses from food and raw material (Yen 2015). Bamboos have many environmental services both at the local and forest ecosystem level. At village level, it protects traditional houses from winds, provides raw material for house construction and fuelwood (Nath et al. 2009). Bamboo requires less fertilizers and pesticides for its management as compared to other cash crops. Its fast growth rate and high annual regrowth bamboo have high carbon stock potential (INBAR 2010). With the growing demand for timber, bamboo is a viable alternative/substitute for timber. At forest ecosystem-level bamboo is vital for the rehabilitation of degraded lands, controlling soil erosion and watershed protection (INBAR 2006; Kaushal et al. 2019; 2020).

The carbon sink potential of the bamboo forest is quite high due to the faster growth rate coupled with quick regeneration capacity (INBAR 2010). It has the capability of becoming one of the best vegetation for mitigating climate change-related problems (Yadava and Thokchom 2014). However, the potential of bamboo in providing critical ecosystem services remains unexplored specifically in terms of carbon farming and subsequently, carbon trading. With this background, a field trial laid to evaluate the best suitable species for biomass production and nutrient cycling among different bamboo species.

MATERIALS AND METHODS

Study site

The study was carried out at experimental field of Department of Silviculture and Agroforestry (30° 51' N latitude and 76° 11' E longitude) at Nauni, Solan - Himachal Pradesh in India (Fig. 1). The elevation of the experimental site is 1200 m amsl. Climatically, the site falls in sub-tropical region but is slightly skewed towards the temperate climate and hence is regarded as a transition zone between sub-tropical and temperate climate. The area experiences a wide range of temperature with a minimum of 1˚C in December and January months to a higher of 37˚C in May and June. A fair amount of frost accompanies the winter, but snowfall rarely witnessed. The area receives on an average 1100 mm rainfall > 70 % of which is received during July-September months.

Experimental setup and field observations

Seven species selected for the experiment were D*endrocalamus asper, Dendrocalamus hamiltonii, Bambusa tulda, Phyllostachys aurea, strictus, Melocanna baccifera, Phyllostachys bambusoides.* The plants were spaced at 5 x 5 meters. The species were grown in the year 2005, and observations made on growth and biomass parameters in the year 2015.

For recording growth parameters, five clumps were randomly selected for each species and identified with paint marking. Circumference, height, number of culms ha^{-1}, live culms $clump^{-1}$ measured for each species. For above-ground biomass estimation, three clumps randomly selected and from each clump 3 culms from each age group *i.e.* < 1 year, 1-2 year and > 2 year were felled. Three age-classes *i.e.*<1 year, 1–2 years and >2 year were identified (Wimbush 1945; Banik 1993). The felled culms segregated into leaves, branches and stem. Rhizomes and roots were extracted and separated manually for below-ground biomass determination. , The fresh weight of samples, obtained in the field, and subsamples from each component taken to the laboratory in plastic bags. The subsamples were oven-dried at 103°C to constant weight.

Litter (Leaf and leaf sheath) was collected by placing nylon traps of 1× 1 m mounted on a wooden frame randomly under each species. The samples were weighted in the field and after that dried in the oven for dry weight estimation. The total litter biomass was computed by summing the dry weight of the individual component.

Carbon sequestration

For the estimation of carbon content, the samples were oven dried at 75-degree centigrade for 72 hours. Carbon content was determined by heating the samples at

400°C for 6 hours in a muffle furnace and using relations as explained by Negi et al. 2003.

Carbon percent = 100 - {Percent ash weight + molecular weight of O_2 (53.3%) in $C_6H_{12}O_6$}

Carbon density in different plant components determined by multiplying the biomass of culm, leaf, branches, and rhizome with a respective concentration of carbon content. The total carbon storage was determined by summing the C-density of leaves, branches, culms, roots, and rhizomes. The carbon sequestration rate was estimated by deducting carbon density after an active growing season from carbon density before the active growing season (Amado and Bayer2008).

A representative sample of stem, leaf, branch, rhizomes, root, and leaf litter collected from each sample plot. The Leaf samples wascollected as per the procedure adopted by Verma et al. (1992). Whereas stem and branch samples collected from the upper, middle, and lower portion of the culm. Samples of Roots and rhizomes were also collected and washed in the field.

Plant chemical analysis

The plant sample collected was immediately weighted and brought to the laboratory for chemical analysis. Total nitrogen estimated by the Micro-Kjeldahl method (Jackson 1973). Total P was determined by Vanado-molybdate yellow method using Ultra Spectrophotometer while K, Ca, and Mg were estimated using Atomic Absorption Spectrophotometer. Nutrient uptake in different biomass components estimated following Embayeet al. (2003).Nutrient uptake by the individual component added to calculate the total nutrient uptake.

Soil chemical analysis and nutrient cycling

Three soil samples taken from each species at two different depths D_1: 0-20 cm and D_2: 20-40 cm at two different seasons (before growing season and after the growing season). Organic Carbon (g kg^{-1}) determined by wet combustion method (Walkley and Black 1934); available nitrogen (kg ha^{-1}) by alkaline potassium permanganate method (Subbiah and Asija 1956) using Kjeldahl distillation unit; available phosphorus (kg ha^{-1}) by Olsen et al. (1954) in Spectronic 20 D^+; available potassium (kg ha^{-1}) by neutral 1 N ammonium acetate solution method (Merwin and Peach 1951) using flame photometer; exchangeable calcium (mg kg^{-1}) by neutral 1N ammonium acetate solution (Merwin and Peech 1951) using flame photometer; exchangeable magnesium (mg kg^{-1}) by neutral 1N ammonium acetate solution (Merwin and Peech 1951) using flame photometer; Soil microbial activity (mg CO_2 g^{-1}) soil by CO_2 evolution method - (Parmer and Schmidt 1964); microbial biomass (mg/100 gm soil) by soil fumigation-extraction method (Vance et al.1987); microbial count (× 10^5 cfu g^{-1} soil) by pore plate method (Subbarao 1999).Soil nutrient, uptake of plant nutrient, and nutrient return through litterfall estimated for assessing nutrient cycling. Nutrient cycling worked out on an annual basis by calculating plant nutrient uptake, returns of nutrients through leaf litter, and nutrients retention in plant parts (Shanmughavel and Francis 2001).

Statistical analysis

Data obtained from the study statistically analyzed by using the analysis of variance (ANOVA) for RBD factorial design following the procedure outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSIONS

Bamboo species showed varied growth performance after ten years of establishment (Table 1). Higher average growth characters were in *D. hamiltonii* (Diameter – 6.33 cm; Height – 9.35 meters), which was followed by *D. strictus* (Diameter – 6.06 cm; Height – 8.59 meters) showing statistical differences in height. *P. aurea* was the least performer. The number of culms, as well as number of live culms in each clump, was higher in *B. tulda,* which varied significantly from other species. The least number of culms and live culms in each clump were in *D. strictus* (Table 1).

Total Biomass production was higher in *D. asper* (48.82 Mg ha^{-1}) followed by *D. strictus* (40.87 Mg ha^{-1}). The least total biomass accumulation was in *P. aurea* (11.58 Mg ha^{-1}).

Many studies have indicated significant variation in the growth of different species, like *D. strictus* and *B. bambos* (Srivastava et al. 2008), rattans (Renuka et al.2004). Field trial of micropropagated species of *B. balcooa, B. bambos, D. asper, D. strictus, D. stocksii, D. asper,*and *G. angustifolia* also showed varied performance (Rathore et al.2009). The estimated total aboveground biomass using developed allometric model was 18.91 Mg ha^{-1} in6 years and 109.30 Mg ha^{-1} in 20 years old plantation (Kaushal et al. 2016). Singh and Singh (1999) have reported bamboo biomass of 46.9 t $ha^{-1}y^{-1}$ in the 3- year old to 74.7 t $ha^{-1}y^{-1}$ in the 5-year old plantation in a dry tropical deciduous forest in India. Embaye et al., 2004 also opined that *Yushania alpina* recorded lesser biomass compare to other species because of its hollow nature which leads to lower specific gravity and hence lesser biomass. Quite lower biomass production values have also reported for *D. strictus*.

, The contribution of above biomass to total biomass, varied from 67 to 74 per cent. The higher contribution of above ground biomass was in *D. hamiltonii* (74 %) and least in *D. asper* (67 %) (Fig. 2). Total biomass was comparatively higher in *D. strictus* may be due to its solid culm from inside despite having the least number of culms per hectare. Biomass partitioning, on per culm basis, is given in Fig. 3. It found that stem contribution to total biomass varied from 26 to 51 % being higher in *D. strictus*, leaf portion to total biomass varied from 6 – 16 % and was higher in *P. aurea*. The contribution of rhizome biomass varied from 23 – 26 % and was higher in both the species of genus *Phyllostachys*. Roots contributed the least (1 -3 %) to total biomass. Singh and Singh, 1999 reported a 51 % contribution of the stem to total biomass in five-year-old plantation of *D. strictus*. Nath et al. (2009) reported higher contribution of stem to total above ground biomass. They reported 86% contribution by culm component followed by branch (10%) and leaf (4%) in above ground stand biomass of bamboo. Embaye et al. 2005 also observed higher culm contribution of 82%, branch 13% and leaf 5% for 110 t ha^{-1} total above ground biomass. Shanmughavel et al (2001) reported that culms contributed about 81% of the biomass in *B. bambos*. Similarly, Kumar et al. (2005) reported about 80% of the biomass in culm wood. The twig biomass varied from 21.65 kg per clump (4x4 m) to 64.04 kg per clump (12x12 m). Yiming et al.(2000) found a leaf biomass of 3.37 Mg ha^{-1} in *D. latiflorus*.

Litter production

Litter production segregated into leaf litter and leaf sheath (Fig. 4). It found that total litter production varied from 0.81 kg m^{-2} in *P. aurea* to 1.57 kg m^{-2} in *D. asper*. In all species, expect *B. tulda*, the sheath contribution to total litter was less than 10 %. In *B. tulda* it was 27 % (Fig. 4). Higher leaf litter production under *D. asper* confirms the statement of that faster a species grows, more litter it would produce with regards to the percentage contribution of litter components (Penfold and Willin 1961). Similar results have been reported at Karnataka (Rai and Procter 1986), Dehradun (Raizada and Srivastava1986) and Coimbatore (Singh *et al.,* 1989). 0.909 kg m^{-2} leaf litter have been reported for *B. bambos* in Kerala (Kumar et al. 2005). Thevathasan et al. (2004) reported high soil organic matter adjacent to tree rows as a result of more litterfall inputs and fine root turnover compared to wide rows.

Carbon accumulation

Carbon density was determined before as well as after the growing season of bamboos (Table 2). It was observed that biomass carbon accumulation increased in a season varied from 1.59 to 6.83 Mg ha^{-1} among different species. Within the same period, the soil carbon density decreased in a range of 1.13 to 10.18 mg ha^{-1}. Overall, the carbon density of the system decreased being higher (7.67 Mg ha^{-1}) in *P. aurea* and lower (2.01 Mg ha^{-1}) in *D. asper*. The only

Table 1. Growth and number of culms of bamboo species

Bamboo species	Culm diameter (cm)	Culm height (m)	Number of culms ha^{-1}	Live culm clump^{-1}
D. asper	5.07^{b}	3.98^{c}	2933.33^{b}	9.11^{b}
D. hamiltonii	6.33 ^{a}	9.35^{a}	2955.56^{b}	7.78^{c}
B. tulda	2.71^{c}	8.23^{b}	5466.67^{a}	10.56^{a}
P. aurea	1.70^{d}	3.15^{d}	2666.67^{b}	8.22^{b}
D. strictus	6.06^{a}	8.59^{b}	2177.78^{b}	7.00^{c}
M.baccifera	2.27^{c}	3.68^{c}	2266.67^{b}	7.33^{c}
P. bambusoides	2.54^{c}	3.44^{d}	2222.22^{b}	7.89^{c}
CD 0.05	0.79	0.47	1649.96	0.95

Different alphabets (a,b,…f) represents statistically different values

Table 2. Carbon density before and after the active growing season

Bamboo species	Before the active growing season				After the active growing season			
	Biomass carbon density (Mg ha^{-1})	Soil carbon density (Mg ha^{-1})	Leaf-litter carbon density (Mg ha^{-1})	Total season carbon density (Mg ha^{-1})	Biomass carbon density (Mg ha^{-1})	Soil carbon density (Mg ha^{-1})	Leaf-litter carbon density (Mg ha^{-1})	Total season carbon density (Mg ha^{-1})
D. asper	13.00^{a}	79.96^{b}	0.40^{a}	93.36^{a}	19.83^{a}	71.31^{b}	0.21^{a}	91.35^{a}
D. hamiltonii	12.50^{a}	82.99^{a}	0.06^{d}	95.55^{a}	16.82^{b}	72.81^{a}	0.11^{c}	89.74^{a}
B. tulda	5.85^{d}	73.94^{d}	0.21^{c}	80.00^{c}	9.71^{d}	67.77^{c}	0.02^{d}	77.50^{c}
P. aurea	2.32^{f}	77.05^{c}	0.29^{b}	79.66^{c}	4.62^{f}	67.27^{c}	0.10^{c}	71.99^{d}
D. strictus	12.01^{b}	78.86^{b}	0.36^{a}	91.30^{b}	17.41^{b}	71.27^{b}	0.21^{a}	88.89^{b}
M. baccifera	3.79^{e}	70.09^{e}	0.31^{b}	74.19^{d}	5.38^{e}	64.23^{e}	0.17^{b}	69.78^{e}
P. bambusoides	6.59^{c}	67.66^{f}	0.09^{d}	74.34^{d}	11.03^{c}	66.53^{d}	0.05^{d}	77.61^{c}
CD at 5%	0.62	1.22	0.05	2.31	0.64	0.94	0.03	1.76

Different alphabets (a,b,…f) represent statistically different values.

Table 3. Microbial activity under different bamboo species

Species	Actinomycetes count (10 ^{5}cfu g^{-1})	Bacteria (10 ^{5}cfu g^{-1})	Fungi (10 ^{5}cfu g^{-1})	Microbial biomass carbon (mg MB-C/100 g soil)
D. asper	9.52^{a}	188.50^{a}	3.48^{a}	131.85^{a}
D. hamiltonii	8.38^{a}	186.32^{b}	3.31^{a}	128.92^{b}
B. tulda	5.17^{c}	176.00^{f}	1.95^{c}	118.08^{f}
P. aurea	6.59^{b}	180.63^{d}	2.42^{b}	122.30^{d}
D. strictus	6.89^{b}	184.47^{c}	2.69^{b}	127.54^{c}
M. baccifera	6.05^{b}	178.05^{e}	2.04^{c}	120.56^{e}
P. bambusoides	4.20^{c}	172.44^{g}	1.86^{c}	112.93^{g}
CD	1.71	1.42	0.57	1.09

Different alphabets (a,b,…f) represents statistically different values

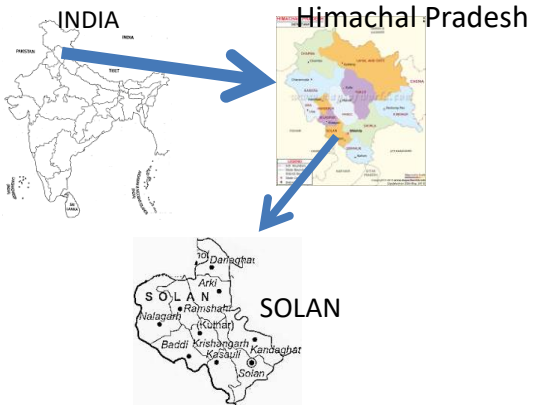

Fig 1. Location of the study site

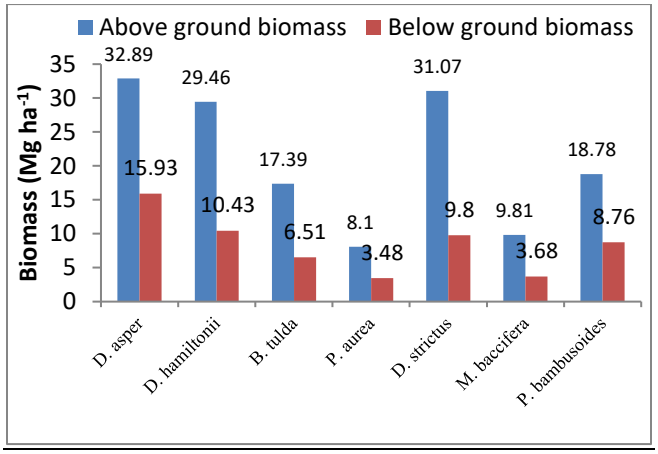

Fig 2. Above and below ground biomass production (Mg ha^{-1}) of bamboos

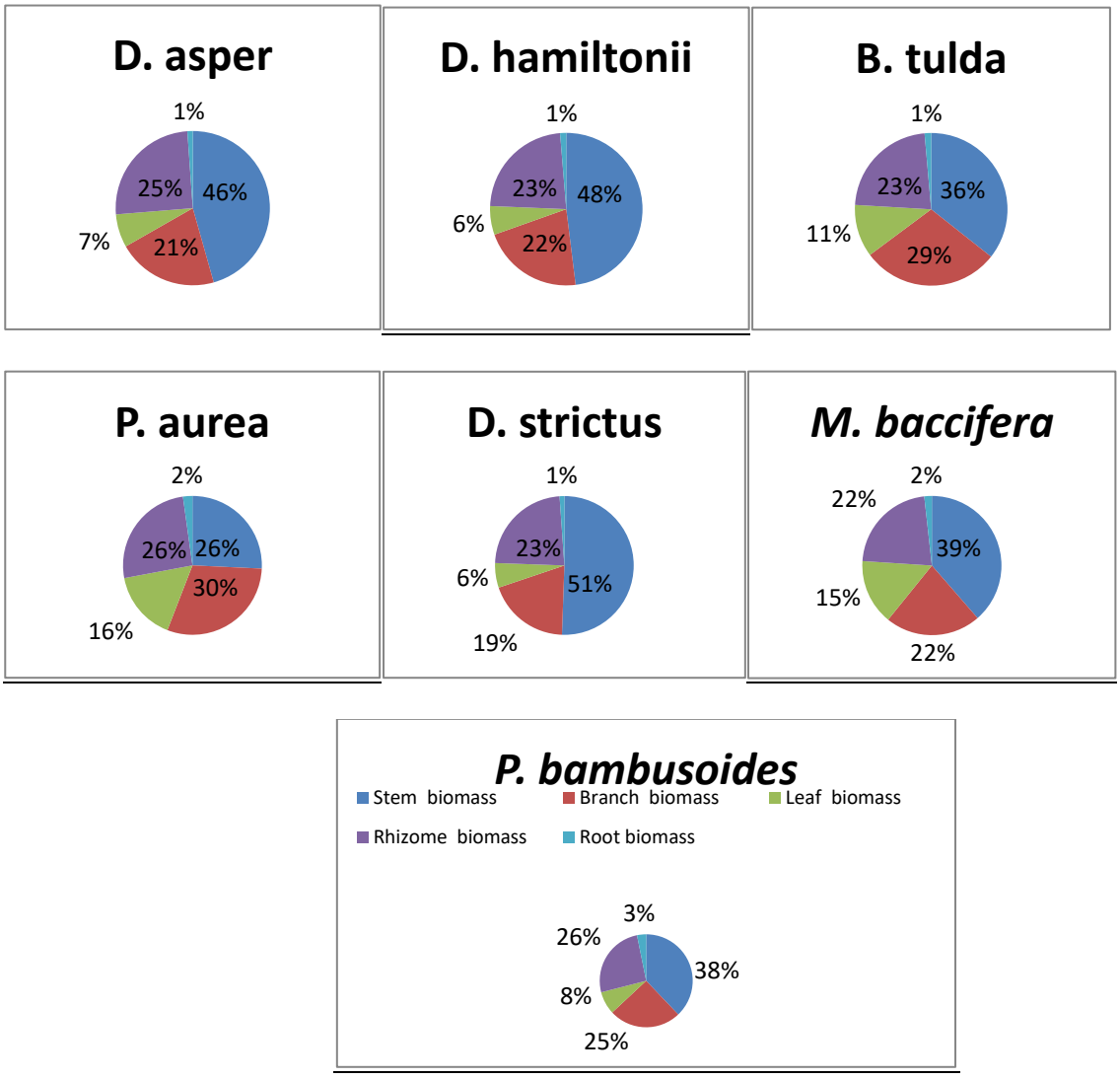

Fig 3. Biomass Partitioning of different bamboo species

species which showed positive carbon density (3.27 Mg ha^{-1}) was *P. bambusoides*. Below (2.41 Mg ha^{-1} $year^{-1}$) and above-ground biomass carbon sequestration rate (4.57 Mg ha^{-1} $year^{-1}$) was higher in *D. asper* and least in *M. baccifera* (0.46 Mg ha^{-1} $year^{-1}$ and 1.12 Mg ha^{-1} $year^{-1}$ respectively) (Fig. 5).

The C amount in aboveground biomass varied from 6.51 (2004) to 8.95 (2007) Mg ha^{-1} with 87%, 9%, and 4% of the total C stored in culm, branch and leaf, respectively. The mean rate of C sequestration was 1.32 Mg ha^{-1} yr^{-1}. Higher biomass and leaf litter carbon density directly related with biomass and litter production on a per hectare basis. Nath et al. (2015), while reviewing biomass and carbon sequestration of bamboo species, concluded that bamboo biomass carbon storage and sequestration rate of 30–121 Mg ha^{-1} and 6–13 Mg ha^{-1} yr^{-1}, respectively in woody bamboos are comparable with agroforestry and forest ecosystems and hence. The rate of C accumulation varies with plantation age, site condition, species, and stand density. The potential carbon accumulation rate in smallholder agroforestry systems in the tropics varies from 1.5 to 3.5 Mg C ha^{-1} yr^{-1} (Watson et al. 2000). Bamboos can be a good sink of atmospheric carbon due to high productivity and a very fast growth rate (Nath and Das 2012). Estimation of carbon partitioning showed that higher proportions of carbon are found in leaves (54-55%), followed by twigs (48-50%), clump wood (44-46%), and dried culm (40-43%) (Kittur 2011). Nath et al.(2009) reported higher carbon allocation (53.05 t ha^{-1}) in clum component of *B. cacharensis* than in branch (5.81 t ha^{-1}) and leaf (2.19 t ha^{-1}). Carbon content in different components of *D. strictus* were: culm-48.66%, branch-48.09% and leaf-44.68%. The total biomass carbon stocks estimated were 8.39 and 49.08 Mg ha^{-1} in 6 and 20-year old plantations (Kaushal et al. 2016). Yen et al.(2010), while comparing carbon accumulation of Moso bamboo with forest trees reported that Moso bamboo forest ecosystem fixed 1.69 and 1.63 times as much C (9.64 t C $ha^{-1}year^{-1}$) as the Chinese fir and Masson pine forest ecosystems, respectively.

Microbial count and nutrient cycling

All microbial counts were higher in *D. asper* followed by *D. hamiltonii* and least in *P. bambusoides* (Table 3). All the parameters showed statistical difference among different species. MBC ranged from 112.93 to 131.85 mg per 100 g of soil. The addition of carbon and nitrogen through litterfall increases microbial biomass. As the litter layer builds up, the microbial population in soil may progressively become dominated by fungi (Hendrix et al. 1986). The increasing dominance of fungi in microbial biomass during grassland restoration has been reported (Bentham et al. 1992). Fungi and bacteria have considerably different C: nutrient ratios. Compared with the higher turnover rate and C losses of the bacterial population, the dominance of fungi promotes higher retention of microbial-C (Singh and Singh 1995). Positive relationships between microbial biomass and soil structure, aggregate size and aggregate stability have already been reported (Singh and Singh 1995). Hence, the rapid development of microbial biomass in the mine spoil is an indication of the efficient restoration potential of *D. strictus* (Singh and Singh 1999). Wang et al. (2004), while comparing Bamboo, Chinese Fir, Citrus orchard, and rice field, found higher microbial carbon B:C levels in the bamboo system than in other systems.

Available soil N, P, K, and exchangeable Ca and Mg given in Table 4. Component wise (leaf, stem, branch) plant nutrient content assessed, and uptake of nutrient per season was arrived by multiplying with the biomass accumulated in the season and returned through litterfall. Higher plant nutrient uptake was in *D. asper* and least in *P. bambusoides* (Table 4).The difference among nutrients absorbed through biomass growth and return through litterfall showed a deficit of nutrients returned to the soil. The higher deficit was for nitrogen (21.06 - 24.95 kg ha^{-1}) and lowest for potassium (11.53 to 21.52 kg ha^{-1}). Mechanism of nitrogen deficit in *D. asper*

Table 4. Soil available nutrient, plant nutrient uptake, and deficit under different bamboo species

Bamboo species	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca* (mg kg^{-1})	Mg* (mg kg^{-1})
Available Soil nutrient					
D. asper	333.77^{a}	44.08^{a}	319.52^{a}	818.63^{a}	626.49^{a}
D. hamiltonii	332.20^{b}	43.67^{a}	318.39^{b}	817.57^{a}	625.88^{a}
B. tulda	319.25^{d}	39.57^{d}	314.11^{d}	811.03^{b}	618.55^{d}
P. aurea	319.45^{d}	40.27^{d}	315.55^{c}	811.61^{b}	619.04^{d}
D. strictus	331.47^{b}	44.02^{a}	318.89^{a}	817.81^{a}	625.56^{b}
M. baccifera	324.30^{c}	41.13^{b}	315.49^{c}	811.88^{b}	619.99^{c}
P. bambusoides	315.87^{e}	39.22^{e}	314.19^{d}	811.77^{b}	617.59^{e}
CD	1.02	0.71	0.72	1.44	0.75
Plant nutrient uptake (kg ha^{-1})					
D. asper	231.38^{a}	41.89^{a}	201.59^{a}	47.46^{a}	58.95^{a}
D. hamiltonii	216.02^{b}	36.34^{b}	190.20^{b}	41.85^{b}	53.32^{b}
B. tulda	188.12^{e}	29.59^{d}	161.75^{e}	27.68^{e}	39.49^{e}
P. aurea	195.54^{d}	33.43^{c}	167.50^{d}	32.86^{d}	44.09^{d}
D. strictus	204.49^{c}	36.84^{b}	182.50^{c}	37.51^{c}	48.89^{c}
M. baccifera	168.35^{f}	27.83^{e}	149.00^{f}	25.33^{f}	37.45^{f}
P. bambusoides	165.47^{g}	26.28^{e}	141.02^{g}	24.21^{g}	35.17^{g}
CD	2.54	1.41	3.23	1.60	1.74

The nutrient deficit created by bamboo species

Nutrients	*D. asper*	*D. hamiltonii*	*B. tulda*	*P. aurea*	*D. strictus*	*M. baccifera*	*P. bambusoides*
N	21.62	21.06	23.71	22.05	21.19	24.95	24.5
P	18.95	18.09	19.42	18.41	18.74	19.98	19.38
K	13.77	13.19	13.47	11.53	13.8	21.52	20.19
Ca	16.56	16.46	17.08	16.56	16.48	16.77	16.68
Mg	17.96	17.98	19.34	18.89	18.44	19.27	19.38

**Exchangeable*

is given in Fig. 6, which indicates that most of the nutrient uptake is retained in the culms and will eventually be removed and not available back to the system. Total nutrient accumulation was 5 t ha^{-1} in 278 clumps ha^{-1}. The nutrient removal through the harvest of bamboo from the plantation site was 469 kg ha^{-1} per year. However, nutrient addition through litter was 79 kg of nutrient ha^{-1} per year (Singh and Kochhar 2005). Litter associated nutrient return was 48.2, 3.7, and 43.0 g m^{-2} of N, P, and K respectively out of 909 g m^{-2} of litterfall in *B. bambos* (Kumar et al. 2005). Previous workers, too, observed significant K accumulation in bamboo biomass and highlighted its ecological significance (Rao and Ramakrishnan 1989). Singh and Arvind (2012) reported concentration of N, P, Ca, Mn and Zn in different components of biomass in the order of leaves > branches > stems and the concentration of K, Mg, and Fe was in the order: leaves > stems > branches. Another critical pathway of enriching the soil C pool is through the dynamic nature of fine root (Divakara et al. 2001, Kaushal et al. 2017). Trees allocate a large proportion of gross primary

production belowground, which in turn contributes to the maintenance of roots and mycorrhizae (Giardina and Ryan 2002), and this general rule holds for bamboo, as well. More than half of the C assimilated by the plant is transported belowground through turnover of the root, root exudates, and litter deposition (Kumar 2008).

CONCLUSIONS

Biomass carbon accumulation increase, in a season, varied from 1.59 to 6.83 Mg ha^{-1} among different species. Within the same period the soil carbon density decreased in a range of 1.13 to 10.18 mg ha^{-1}. Only species which showed positive carbon density (3.27 Mg ha^{-1}) was *P. bambusoides*. Due to higher growth rate below (2.41 Mg ha^{-1} year^{-1}) and above-ground biomass carbon sequestration rate (4.57 Mg ha^{-1} year^{-1}), litter return (1.57 kg m^{-2}) and MBC (131.85 mg per 100 g of soil) were higher in *D. asper*. Comparison for biomass production and nutrient cycling among seven bamboo species reveals higher biomass production in *D. asper* as compared to native species (*D. strictus*). The other potential species with multipurpose use is *D. hamiltonii*. Due to the harvesting of more than 90 percent of the above-ground biomass (stem and branches), as per standard practice, soil nutrient deficiency is created at the site. Thus, it advocated that bamboo plantations should be fertilized to get production in perpetuity without rendering the site nutrient-poor.

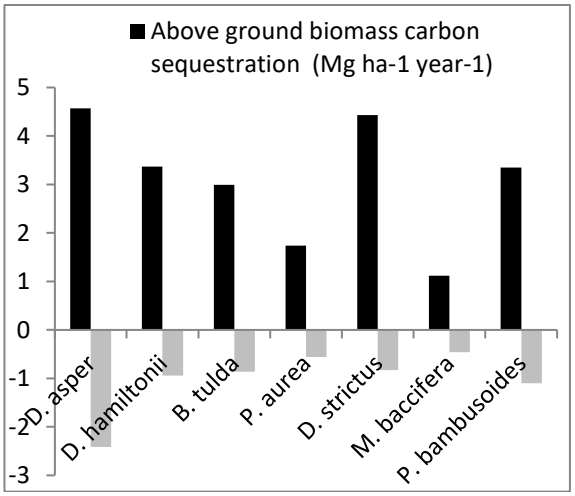

Fig 4. Leaf and sheath litter of species

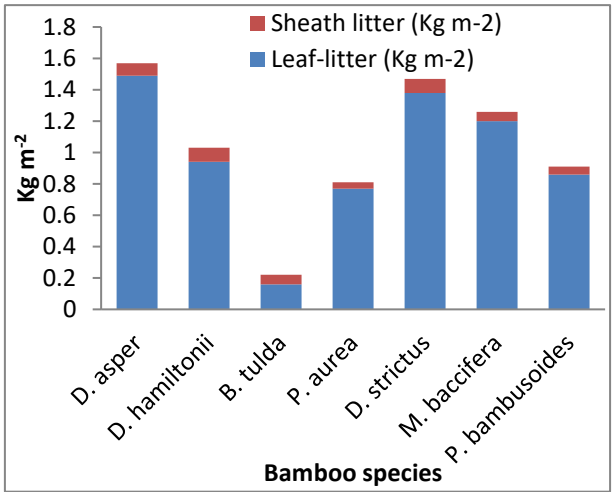

Fig 5. Rate of carbon sequestration

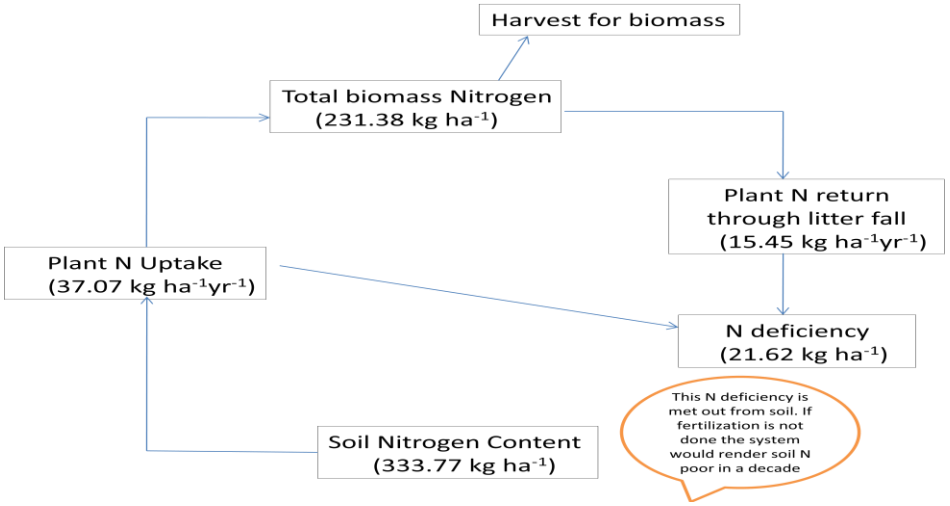

Fig 6. Nitrogen cycling in *D. asper* at 6th year of age

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