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Research Article

Plant and soil carbon stock and carbon sequestration potential in four major bamboo species of North India

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Abstract: With climate change being unequivocal, reducing CO_2 in our atmosphere has become a primary goal of international efforts. Carbon sequestration is the process characteristic of the species employed for plantation but depends on the continuous management of the plantation also. Assessment of carbon stocks in vegetation and soil is a basic step in evaluating the carbon sequestration potential of an ecosystem. The present study was conducted to quantify the total carbon stock and carbon sequestration potential in four bamboo plantation systems (*Dendrocalamus strictus*, *Bambusa vulgaris, Bambusa balcooa* and *Bambusa nutans*) in the Terai belt of Uttarakhand, India for two years. The major parameters of the study involved physicochemical characteristics of the soil, structural and functional attributes of microbes, and carbon stocks and carbon sequestration potential in vegetation and soil. Destructive approach was used for biomass estimation. At the end of the study, soil organic carbon stocks in the plantations *Dendrocalamus strictus*, *Bambusa vulgaris*, *Bambusa balcooa* and *Bambusa nutans* were 106.56 t ha^{-1}, 85.06 t ha^{-1}, 65.40 t ha^{-1}, and 57.28 t ha^{-1} respectively. With this, the highest carbon sequestration potential was observed in *Dendrocalamus strictus* plantation soil. The observed average soil respiration (1426.45mg CO_2 m^{-2} hr^{-1}) and microbial biomass carbon (0.212%) were also highest in *D. strictus* among all species. Carbon stock was found more in biomass than in soil in all bamboo species. Thus, the present study clearly demonstrates that besides being an economic strength bamboo plant have shown encouraging results in the field of carbon sequestration potential also and it can be a better climate change mitigation option because of several environmental benefits.

Keywords: *Bambusa balcooa*, *Bambusa nutans*, *Bambusa vulgaris*, Carbon sequestration, Carbon stock, Climate change, *Dendrocalamus strictus*, Microbial biomass carbon, Soil respiration.

1. Introduction

The late nineteenth century has been an eyewitness of the rise in global surface temperatures by 0.8^0C, and 11 out of the 12 warmest years on record have occurred since 1995 (IPCC, 2007; Lal, 2009). This change in universal climate has stirred an escalating interest of scientific and political communities in the study of global carbon storage and carbon balance (Landsberg *et al.*, 1995; INBAR, 2006). Several eco-friendly policies and forest management practices are under consideration to tackle the impacts of climate change (Ravindranath *et al.*, 2006). Bamboo, a fast growing, versatile woody grass, is considered one of those materials available in nature with which human inventiveness could interact. This ‘green gold’ introduces itself as a cheap and plentiful resource to meet the vast needs of the human population and frequently known as “poor man’s timber” (Ram *et al.*, 2010). Bamboo has emerged as a precious wood substitute in the last 15 – 20 years (Kumar *et al*., 2010). India represents second largest bamboo resources in the world with 130 species that grow naturally at heights ranging from sea level to over 3500m, in about 10

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million hectares of forestland, and on farmlands and private plantations (NMBA, 2004; Nath, *et al.*, 2009; Naithani, 1993). Bamboo which is sometimes called 'the grass of hope' (PIA, 2008) is a miracle plant with over 1500 recorded uses (Ranjan, 2001).

Bamboo has been potential substitute for two essential natural resources: timber and fabric in the past few years, but there are still some more research aspects continually expanding the scope of uses for bamboo (Scurlock *et al*., 2000; Ghavami, 2005). Being an economic resource with huge potential for humanizing quality of rural and urban life it is also blessed with environmental fortification qualities like carbon sequestration. Preliminary results in bamboo show that it can absorb 12 metric tons of harmful carbon dioxide per hectare from the air, which is twice that of a similar size forest (Choudhary, 2008; Scurlock *et al*., 2000). A similar study by Venkatesh *et al*., (2005) concluded that organic carbon increased in soils under all the species of bamboo. Due to their fast growth and high productivity bamboos can be noteworthy as a sink of atmospheric carbon (Nath *et al.*, 2007; Nath *et al.*, 2008).

In India, Bamboos form the vital component of agrosilvicultural systems and have an important influence on the C balance of ecosystem through assimilating atmospheric CO_2 (Nath *et al*., 2011). Although, there is ample literature available on bamboo related to its socioeconomic worth especially both for rural and urban people but there is very little research has been done so far on its role in the carbon cycle (Kumar *et al*., 2010). Studies on carbon sequestration potential in bamboo are scarce and most of these studies are carried out in natural plantations. In previous studies, the main emphasis was given either on soil carbon or on plant carbon storage in agrosilvicultural systems but the present study focuses on total carbon storage and sequestration potential in bamboo plantations along with soil carbon in most common species of bamboo in the North Indian region. For this, four main species of bamboo in North India were selected (*Dendrocalamus strictus*, *Bambusa vulgaris*, *Bambusa balcooa* and *Bambusa nutans*) which are most frequently cultivated and have great economic value.

2. Materials and Methods

2.1 The species

D. strictus, *B. vulgaris*, *B. balcooa* and *B. nutans* are widely distributed and frequently cultivated bamboo species in the North Indian region although their origin is the North Eastern region of India. *D. strictus* is native to India, Nepal, Bangladesh, Myanmar and Thailand and cultivated in many other countries of SE Asia. *B. vulgaris* is cultivated in many parts of the world, in India mainly in the North East and also in many other parts of the country. Origin of *B. balcooa* is said to be from NE India but at present, it is mostly cultivated in different countries and now is introduced to Australia. *B. nutans* are commonly grown in the lower Himalayan region extending southwards to Bangladesh and Thailand is also one of the most widespread species of bamboo in India.

2.2 Description of the Experimental Study Sites

The field study was conducted for two years (July 2009 to July 2011) in two different sites of the Terai region of Uttarakhand, India namely Agroforestry Research Centre (AFRC), Haldi, Pantnagar; and Gangapur Patia, Udham Singh Nagar. The region is located at 29^0N Latitude, $79^0$3'E Longitude and at an altitude of 243.84 meters above the mean sea level. The area lies in the Terai belt of the Shivalik range of the Himalayan foothills and falls in the subhumid and subtropical climate zone. Average rainfall is 140.55mm, most of which is received during the southwest monsoon season (May – September). The mean maximum temperature ranges from 15.72^0C (January) to 39.22^0C (June). The mean minimum temperature ranges from 7.0^0C (January) to 27.65^0C (June). Characteristics of all the species are given in Table 1.

Table 1. Characteristics of the plantation sites.

S. No.	Species	Area (ha)	Tree Density (Stem ha^{-1})	Age (Year)	Bulk density of soil (g cm^{-3})	Water holding Capacity (%)
1.	*D. strictus*	1.5	556	7	1.31	78.05
2.	*B. vulgaris*	1.5	556	7	1.24	56.41
3.	*B. balcooa*	1.0	400	5	1.52	85.05
4.	*B. nutans*	1.0	400	4	1.48	81.41

2.3 Biomass determination

Biomass were determined by destructive method by harvesting randomly selected culms of different sizes. Depending on the culm sizes 7 (seven) different girth classes each for *D. strictus* and *B. vulgaris*, 5 (five) different girth classes for *B. balcooa* and 4 (four) different girth classes for *B. nutans* were recognized representing the whole diameter range. After harvesting, culm samples were divided into leaf, branch and culm components and their respective fresh weights were taken in the field. A subsample of each component was oven dried at 70^0C to a constant weight to calculate the dry matter of each component.

2.4 Above and belowground biomass carbon stock

Aboveground biomass estimation was done by harvest method. For this, culms of bamboo plantations were felled in the field and delimbed. Subsamples of culm were cut and weighed infield for the fresh weight of the disc. The subsamples were transported to the laboratory and oven dried at 65^0C for 76 hrs till the constant weight was achieved. The carbon was determined using an ash content method (Gallardo and

Merino, 1993). In all the bamboo species, biomass in the belowground component were assumed to be the 26% of above ground biomass (Singh *et al.*, 2006). The carbon pool study is incomplete without litter study. Therefore, Litter floor mass was collected at 3-month intervals, from 10 different plots of 50cm × 50cm sized quadrate laid randomly at each occasion. From each plot, floor mass was separated into leaf, sheath and branch litter and weighed separately. Subsamples were collected and oven dried at 70^0C to a constant weight. Oven dried samples were powdered for further analysis. The biomass carbon stock was estimated by multiplying total plant biomass (ton ha^{-1}) with carbon concentration (%).

2.5 Soil chemical characteristics along with soil organic carbon stock

For determining the soil physicochemical properties soil was sampled at two depths i.e. surface layer (0-15cm) and subsurface layer (15-30cm). A composite sample was prepared for each depth, air-dried, ground and passed through a 2mm sieve and stored in plastic container. Bulk density was determined according to the method outlined by Allen *et al*., (1974). The moisture content was determined gravimetrically and pH was measured in a solution of soil and distilled water (1:25 w/v). The organic carbon content of the soil samples was examined by Walkley and Black's rapid titration method (Walkley and Black, 1934). Available (mineralizable) nitrogen was determined by the alkaline permanent method (Subbiah and Asiji, 1956). The Olsen's method (Olsen *et al*., 1954) was used for determining available phosphorus in the soil whereas available potassium in soil was determined by flame photometer using neutral normal ammonium acetate method of Black (1965). The soil carbon stock was computed by multiplying the soil organic carbon (g kg^{-1}) with bulk density (g cm^{-3}) and depth (cm) and is expressed in ton ha^{-1} (Joao Carlos *et al.*, 2001).

2.6 Microbial Biomass Carbon in the soil

Soil microbial biomass C (MBC) was estimated following chloroform fumigation-extraction method (Vance *et al*., 1987). For each site, out of six subsamples (each containing 10g fresh soil), three were fumigated with ethanol-free chloroform for 24 hrs. After removal of chloroform, the soil was extracted with 0.5M K_2SO_4 (using a soil: solution ratio of 1:4) by shaking for 30 min. Remaining three subsamples being not fumigated were treated as control and also subjected to 0.5M K_2SO_4 extraction. The extracts were filtered through Whatman filter paper (No. 42). The filtrates were analysed for organic C by dichromate oxidation (Vance *et al.*, 1987). Microbial biomass C was calculated as-

$$\mathbf{C_{mic} = EC/k_{EC}}$$

Where, EC = (Total organic carbon extracted from fumigated soil) - (Total organic carbon extracted from non-fumigated soil), and k_{EC} = 0.45, a proportionality factor for converting the EC value to C_{mic} (Wu *et al*., 1990; Klose *et al*., 1999).

2.7 Soil respiration analysis

Soil respiration in the samples (three samples from each site) collected from different sites was measured regularly following the alkali absorption technique (Witkamp, 1966). For this, fresh soil of 500g was placed in a glass container (2 L capacity) and its moisture content was adjusted to 60% by adding sterile water. The samples were incubated at room temperature (28 ± 4^0C) for 1 week to settle down the respiration and then the respiration in terms of CO_2 evolution was measured.

2.8 Total Carbon stock (plant + soil) and carbon sequestration potential

Total carbon stock (plant carbon stock + Soil carbon stock) was obtained by summing up the soil and plant carbon stocks in both types of ecosystems. Carbon sequestration in bamboo plantations was calculated by subtracting carbon stock values (t ha^{-1}) of first year by second year (Nath *et al*., 2011). In this way the carbon sequestration obtained in the form of t ha^{-1} yr^{-1}.

2.9 Statistical analysis

All the data collected for different experiments and field samples during the study were compiled and processed for statistical treatment. The data were analyzed for the mean and standard error. Analysis of Variance (ANOVA) was used to test the significance of difference between treatment means.

3. Results

3.1 Soil chemical parameters

Fig. 1 (a), (b) and (c) show average Available soil nitrogen, available phosphorous and available potassium in four plantations sites at both depths. At both the depths (0-15cm and 15-30cm) *D. strictus* have recorded maximum available nitrogen concentration in the soil throughout the study period [272.71 kg ha^{-1}, 305.74 kg ha^{-1} (at 0-15cm in both years), and 206.44 kg ha^{-1}, 206.01 kg ha^{-1} (at 15-30cm in both years) respectively] whereas a minimum value was observed in *B. vulgaris* [221.33 kg ha^{-1}, 264.52 kg ha^{-1} (at 0-15cm in both years), and 178.18 kg ha^{-1}, 194.26 kg ha^{-1} (at 15-30cm in both years) respectively]. Available phosphorous and available potassium has also shown highest concentration in the soil of *D. strictus* at the end of study (110.12 kg ha^{-1} and 134.79 kg ha^{-1} respectively). Minimum values of available phosphorous and available potassium differed in both the years with sites and depths.

Overall, the available soil phosphorous content decreased with the increasing depth and with proceeding time. Patil *et al.*, (2004) observed the increase in the available phosphorous content in the *D. strictus* based Agroforestry systems in a one year study whereas Geetha and Balagopalan (2005) observed that the total phosphorous was found to be decreased with the depth in teak and eucalyptus plantations in Kerala. Singh *et al*., (2000) observe seasonal variation in the available phosphorous content in the Agroforestry systems in Rajasthan for one year. They found the soil available phosphorous to be increased in one year as observed in the present study. The available potassium was found to be increased in one year following *D. strictus* plantation in the Agroforestry systems (Patil *et al*., 2004). The potassium content was found to be decreased in lower depths in the present study as observed by Singh *et al*., (1981) in the *D. hamiltonii* and other bamboo plantations.

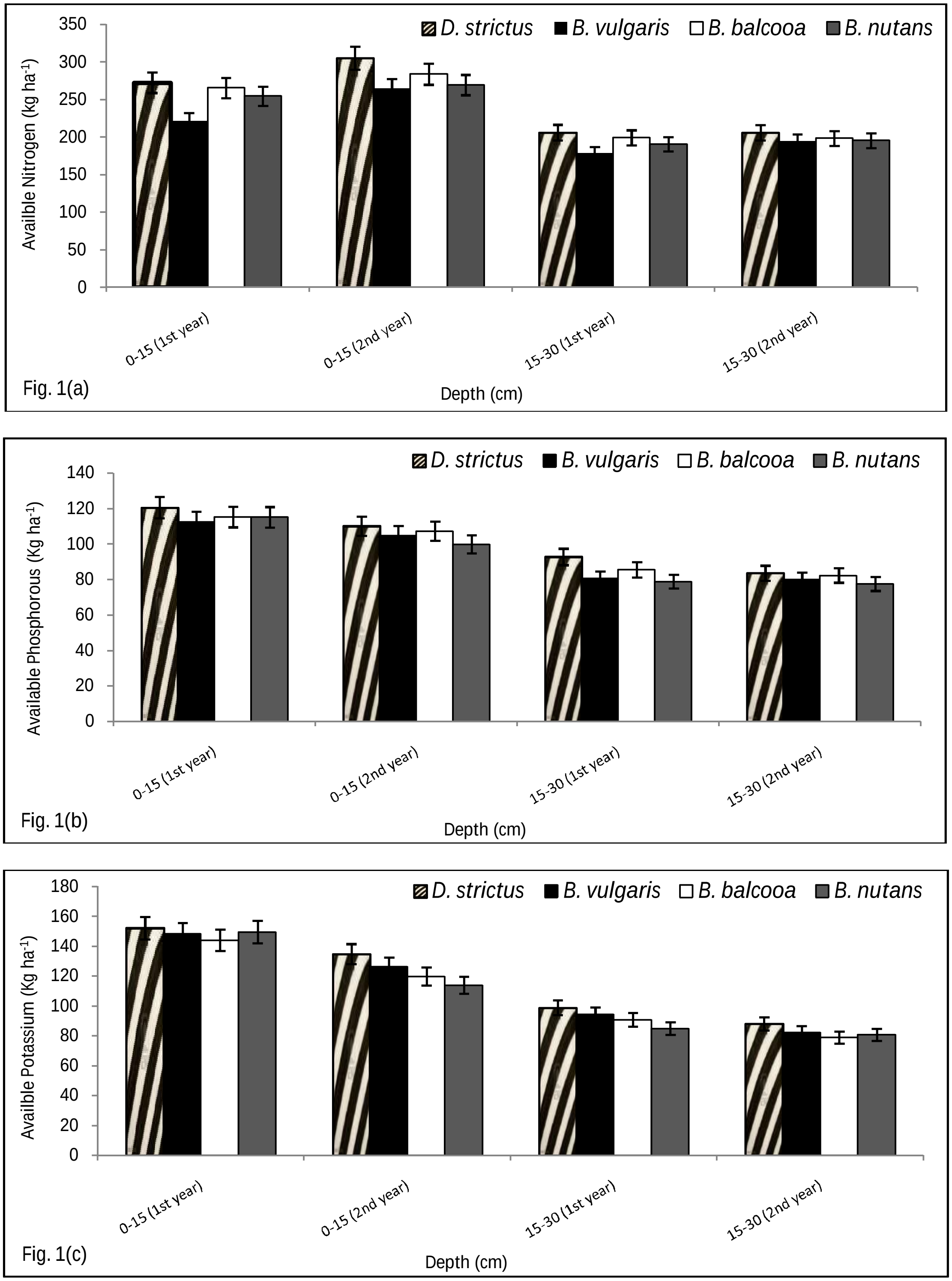

Fig. 1(a,b & c). Change in available soil nitrogen, phosphorous, and potassium in all plantation sites with depth and time.

3.2 Biomass production in all bamboo species

The biomass of different plant components were found to be increased with the age of each plantation. Hence higher biomass were observed in the second year of the study. Table 2 shows aboveground biomass (clump + litter) and belowground biomass in all the four species of bamboo for both the years. During the first year, *D. strictus* plantation has the highest value of total biomass (458.77 t ha^{-1}) followed by *B. balcooa* (324.67 t ha^{-1}), *B. nutans* (216.41 t ha^{-1}) and *B. vulgaris* (121.30 t ha^{-1}). Results on similar pattern were observed at the end of second year also.

3.3 Biomass carbon stock

In the bamboo species, average of the node and Internode carbon concentration was used as the value of carbon concentration for the whole culm. The values of carbon concentration in the culm were observed to be 48.21% for *D. strictus*, 44.61% for *B. vulgaris*, 48.50% for *B. balcooa* and 43.78% for *B. nutans* plantation systems. The initial carbon content of the leaf litter was considered as the carbon concentration. The values of carbon concentration were 28.4% for *D. strictus*, 32.1% for *B. vulgaris*, 32.4% for *B. balcooa*, and 28.6% for *B. nutans* leaf litter. The values for the biomass carbon stock of different components of various plantations are presented in Table 3. The total biomass carbon stock was highest in *D. strictus* (275.94 t ha^{-1}) followed by *B. balcooa* (233.84 t ha^{-1}), *B. nutans* (159.92 t ha^{-1}) and *B. vulgaris* (75.05 t ha^{-1}) at the end of the study.

3.4 SOC stock

The soil organic carbon stock was more in subsurface soil as compared to the surface soil (Table 4). The mean values of soil organic carbon stock increased with time for all the plantation sites. At the end of the study maximum, SOC stock was observed in *D. strictus* (106.56 t ha^{-1}) followed by *B. vulgaris* (85.06 t ha^{-1}), *B. balcooa* (65.40 t ha^{-1}) and *B. nutans* (57.28 t ha^{-1}).

3.5 Soil microbial biomass carbon

Fig. 2 shows the percentage microbial biomass carbon in soils of all bamboo plantation sites with respect to both depths and years. Overall, the soil MBC content decreased with the increasing depth of the soil at all the four study sites while it increased with proceeds time in all sites. According to Dilly *et al*., (2003) and Benbi *et al*., (2004), the amount of C in the soil microbial biomass mostly accounts for 1-5% of the total soil carbon, and its turnover time is less than one year, so present study gave similar results. Wang *et al*., (2004) investigated the levels of MBC in the soil profiles of five different vegetation systems including bare area, Bamboo, Chinese fir, Citrus Orchard and Rice field. The MBC level in surface and subsurface soil for the *D. strictus* was higher than other species (0.212% and 0.1% respectively). However, the difference in MBC was not significant between sites but between times, it was significant. At almost all study sites MBC level was higher during the rainy season (Killham, 1994; Jiang-Shan, 2005).

3.6 Soil respiration activity

Soil respiration was measured in terms of mg CO_2 evolved m^{-2} hr^{-1} in the surface and the subsurface layer in every month at each study site during the two years of study (Fig. 3). *D. strictus* reported higher soil respiration activity due to higher organic carbon content as compared to other three bamboo species as soil respiration is the direct function of microbial populations and carbon availability in the soil (Myrold, 1987). The Labile carbon compounds in the litter are utilized by the microbes and resulted in the release of CO_2 as soil respiration activity (Brady, 1990). Deka and Mishra (1982); Singh (1984) and Upadhyaya *et al*., (2004) observed similar seasonal fluctuation trend of soil respiration activity of soil in the bamboo plantation sites.

3.7 Total Carbon stock (plant + soil) and carbon sequestration potential

Total carbon stock in all sites was computed by adding total biomass carbon stock and SOC stock (Table 5). The highest total carbon stock was observed in *D. strictus* (381.50 t ha^{-1}) while the lowest stock was shown by *B. vulgaris* (160.11 t ha^{-1}). Contrary to this, the maximum carbon sequestration potential was seen *B. balcooa* (99.81 t $ha^{-1}yr^{-1}$) whereas minimum was observed in *B. vulgaris* (57.77 t $ha^{-1}yr^{-1}$).

Table 2. Above and belowground biomass (t ha^{-1}) in various bamboo species.

Plantation	Clump (t ha^{-1})		Litter (t ha^{-1})		Belowground (t ha^{-1})		Total (t ha^{-1})	
	2010	2011	2010	2011	2010	2011	2010	2011
D. strictus	364.02	450.74	0.10	0.14	94.65	117.19	458.77	568.08
B. vulgaris	96.21	130.20	0.08	0.11	25.02	33.85	121.30	164.17
B. balcooa	257.60	380.16	0.09	0.13	66.98	98.84	324.67	479.13
B. nutans	171.72	281.61	0.04	0.10	44.65	73.22	216.41	354.92

Table 3. Above and belowground biomass carbon stock (t ha^{-1}) in various bamboo species.

Plantation	Clump (t ha^{-1})		Litter (t ha^{-1})		Belowground (t ha^{-1})		Total (t ha^{-1})	
	2010	2011	2010	2011	2010	2011	2010	2011
D. strictus	175.49	217.30	0.03	0.04	47.32	58.60	222.85	275.94
B. vulgaris	42.92	58.09	0.03	0.03	12.51	16.93	55.45	75.05
B. balcooa	124.94	184.38	0.03	0.04	33.49	49.42	158.46	233.84
B. nutans	75.18	123.28	0.01	0.03	22.32	36.61	97.51	159.92

Table 4. SOC stock (t ha^{-1}) in all bamboo species.

Plantation	2009-10		2010-11		2010	2011
	0 -15cm	15-30cm	0-15cm	15-30cm	Mean	Mean
D. strictus	52.66	96.95	68.97	144.14	74.81	106.56
B. vulgaris	38.32	55.46	58.40	111.72	46.89	85.06
B. balcooa	36.88	45.07	69.73	61.07	40.97	65.40
B. nutans	30.82	34.73	58.07	56.50	32.77	57.28

Table 5. Total carbon (plant + soil) stock and carbon sequestration potential in all bamboo species.

Study sites	SOC stock (t ha^{-1})		Biomass Carbon stock (t ha^{-1})		Total carbon stock (t ha^{-1})		C seq (t ha^{-1} yr^{-1})
	2010	2011	2010	2011	2010	2011	
D. strictus	74.81	105.56	222.85	275.94	297.66	381.50	83.84
B. vulgaris	46.89	85.06	55.45	75.05	102.34	160.11	57.77
B. balcooa	40.97	65.40	158.46	233.84	199.43	299.24	99.81
B. nutans	32.77	57.28	97.51	159.92	130.28	217.20	86.92

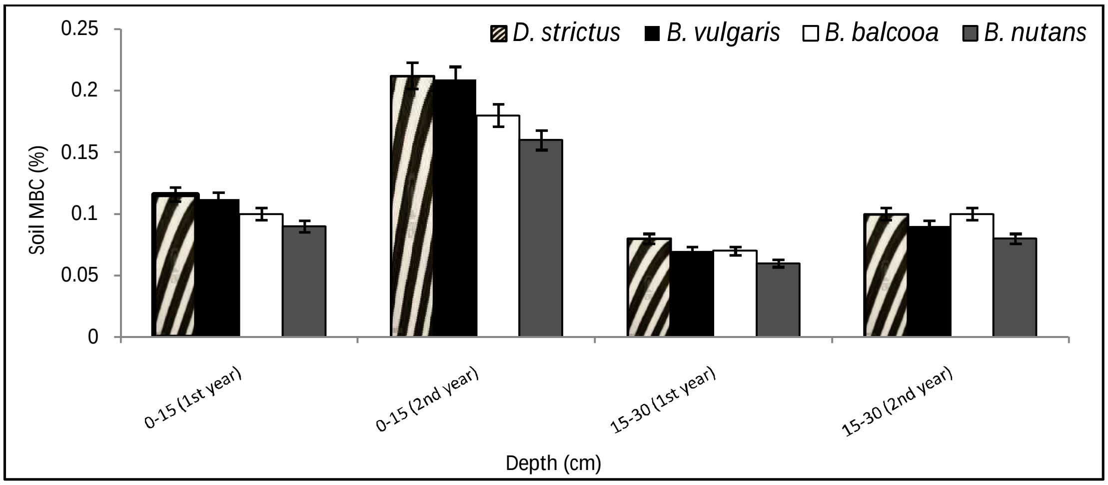

Fig. 2. Variation in soil microbial biomass carbon (MBC) in all study sites with depth and time.

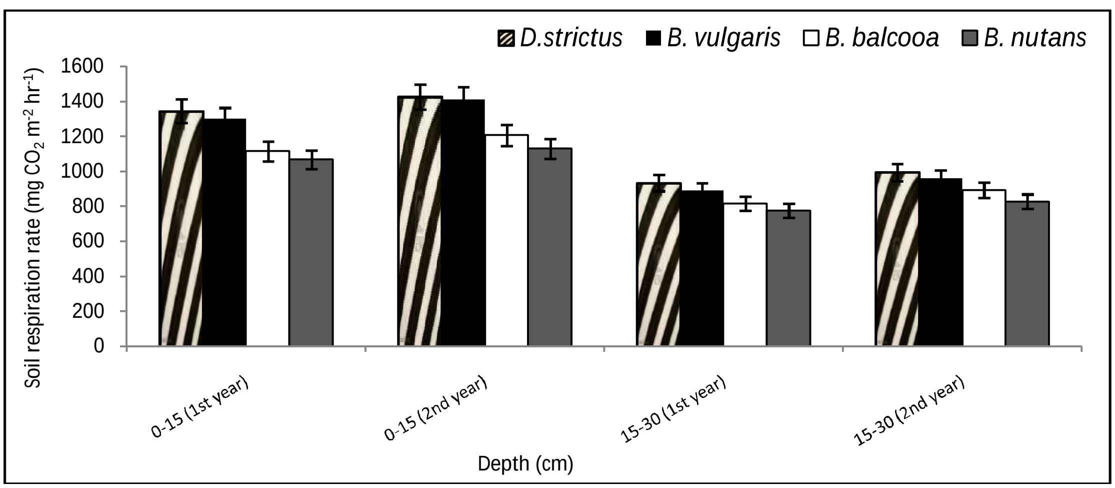

Fig. 3. Variation in soil respiration in all study sites with depth and time.

4. Discussion

The increase in the nitrogen towards the end of the study in most of the plantations signifies the slow mineralization of nitrogen due to decomposition activities of microbes. Decrease in the available nitrogen towards increasing depth may be due to their fast use by the microbes for their growth and functioning at the surface but they're lacking at subsurface (Xue *et al*., 2002; Venkatesh *et al*., 2005).

Singh *et al*., (2006) indicated that biomass allocation of plant depends upon a number of factors, viz., growth habitat of the species, soil quality, soil on which plants are growing, age of the plant, management practices and interaction with belowground vegetation. In the first year of study highest biomass in *D. strictus* (stem density 556 trees ha^{-1}) plantation can be attributed to the fast growth of this particular bamboo species as compared to others. The greater number of culm contributes to more biomass and vice versa. The highest litter biomass was in *D. strictus* plantation can be attributed due to the large spread of the canopy and litterfall.

Aboveground, production in *D. strictus* reported by Tripathi and Singh (1996) and Singh and Singh (1999) were in the range of 4-22 t ha^{-1} and 30-49 t ha^{-1}, respectively. The values in the present study are towards the much higher side than these findings. Possible reason may be the stocking density and quality of planting material because the yield of the plantations depends on the site characteristics and planting material to a greater extent. The culm part of the plantation or the aboveground biomass contributes more towards the total biomass of the clump than the rhizome or the belowground portion (Shanmughavel *et al*., 2001).

The carbon concentration was higher in the culm part of the bamboo as in the nutrient rich soil major biomass is allocated in the aboveground parts (Puri *et al.*, 2002; Swamy *et al*., 2003). The sites in the present study were found to be rich in soil carbon and other nutrients, further, the addition of leaf litter and its fast decomposition supported by climatic conditions add up the nutrient to the soil. A similar trend in carbon concentration was observed by Singh and Singh (1991) for dry tropical forests and Swamy and Puri (2005) for *Gmelina arborea*. Carbon storage in the plantation also depends on the factors as the age and structure of the system (Swami and Puri, 2005; Oelbermann *et al*., 2004; Shrestha *et al*, 2008).

Litter production from plant is one of the major sources of organic matter in soil restoration of agricultural land (Lugo and Brown, 1993). Hosur and Dasog (1995) also reported that due to higher litter production the organic carbon increases. Higher values of soil carbon stock in the present study may be attributed to the high amount of litterfall. The more organic carbon in surface layer can be attributed to more accumulation of leaf litter and fine roots in the upper soil layer which on decomposition releases CO_2 during mineralization of organic carbon and accumulate only resistant products viz. humus in soil.

The MBC is the entire soil microbial population treated as an entity. The soil MBC is a source of nutrients and changes in the MBC can be used to predict the effects of ecosystem perturbations. This is why microbial indicators have been used as reliable tools to characterize soil quality with respect to land use and soil management (Turco *et al.*, 1994; Doran and Parkin, 1994). With the age of plantation, the soil carbon and microbial counts were increased thus supporting the increase in soil respiration activity of soil microfauna in the second year as compared to first year. Subsurface layer showed lesser soil respiration activity as compared to the surface layer in all the study sites (Shrestha *et al.*, 2008). The soil respiration is also found as a linear function of primary productivity of the ecosystem (Janssens *et al.*, 2001; Reichstein *et al*., 2003).

Total carbon stock (plant + soil) depends on many factors like net primary productivity, biomass, litter biomass, carbon addition from the plant into the soil, soil texture and many more. Comparative assessment of total carbon stock of all the sites reveals that *D. strictus* was having higher carbon stock and carbon sequestration potential as compared to other bamboo species (Fig. 4) which may be attributed to its higher productivity, higher biomass, better soil health, higher litter biomass, higher age and best management practice.

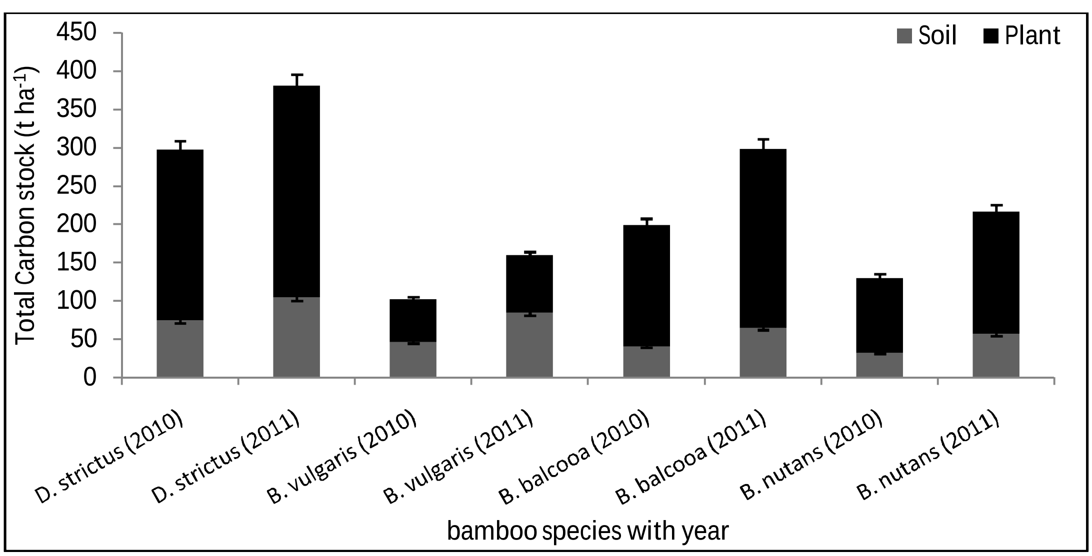

Fig. 4. Comparative soil and plant carbon stocks in all bamboo species with time.

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