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Research Article

Assessment of variation in carbon pool in Bamboo plantation and managed Agricultural system

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Abstract: The present study was conducted to quantify the carbon pool in two different vegetation systems, i.e. bamboo plantation and agricultural fields in the Tarai belt of Uttarakhand, India during 2011-13. Two bamboo plantation sites *viz. Bambusa balcooa*, *Bambusa nutans*, and two agricultural sites *viz.* C_{12}, D_7 were studied. The major parameters of the study involved litter decomposition study, carbon stocks in vegetation and soil, and carbon sequestration potential. The soil organic carbon stocks under the study sites *B. balcooa*, *B. nutans*, C_{12}, and D_7 were 65.40, 57.28, 37.48 and 36.32 t ha^{-1} respectively. Hence, the highest carbon sequestration potential was observed for *B. balcooa* plantation soil. The decomposition and nutrient dynamics in the decomposing leaves of the plantation were studied and regression equations were developed. In agricultural sites where crop rotation was main management practice applied, plant biomass carbon stock and soil carbon stock were estimated. In both sites (C_{12} and D_7), biomass carbon stock was found very significant (5.28 and 5.12 t ha^{-1}). In all sites, total biomass production was highest in *B. balcooa* (479.13 t ha^{-1}) and so biomass carbon stock was too (233.84 t ha^{-1}). Carbon sequestration potential was found more in biomass than in soil in the case of bamboo, but in agricultural sites, it was more in soil than biomass. 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, the study has revealed the importance of agriculture in terms of carbon sequestration potential with the help of good management practices.

Keywords: *Bambusa balcooa*; *Bambusa nutans*; Biomass carbon stock; Carbon pool; Carbon sequestration; Crop rotation; Litter decomposition.

1. Introduction

Currently, biotic carbon sequestration is being considered a viable option for mitigating CO_2 emitted to the atmosphere. Bamboo, being a fast growing grass, known as "Green Gold", is considered as sufficiently cheap and plentiful to meet the vast needs of the masses from the "child cradle to the dead man's bier" that is why sometimes known as "poor man's timber" (Ram *et al.*, 2010). Apart from the ability of environmental regeneration like carbon sequestration, it is an economic resource with immense potential for improving quality of rural and urban life (Choudhary, 2008). The most widely known features of bamboo are its fast growth, adaptability, resilience and substantial biomass production. In 15 – 20 years, it has emerged as a valuable wood substitute (Kumar *et al.*, 2010). Development of bamboo resources and industries worldwide, promotes economic and environmental growth, mitigates deforestation and illegal logging, prevent soil degradation and restores degraded lands (Scurlock *et al.*, 2000; Kumar *et al.*, 2010). These qualities of bamboo have been well studied and are widely known (Choudhary, 2008; Scurlock *et al.*, 2000; Kumar *et al.*, 2010). Bamboos are distributed all over the world, but major species richness is found in Asia Pacific (Bystriakova *et al.*, 2003). India's bamboo resources are the second largest in the world with 130 species that grow naturally (NMBA, 2004; Nath *et al.*, 2009). Bamboos can be significant sinks of atmospheric carbon (C) due to their fast growth and high productivity (Nath *et al.*, 2008). Finding low-cost methods to sequester C is emerging as a major international policy goal in the context of global climate change (Nath *et al.*, 2008; Nath *et al.*, 2011). It is essential to evaluate the role of village bamboos in C

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sequestration to understand its effectiveness in atmospheric CO_2 mitigation. Bamboos in India form an imperative component of agrosilvicultural systems and have an important influence on the C balance of ecosystem through assimilating atmospheric CO_2 (Nath *et al*., 2011).

Though carbon emissions from agricultural activities contribute to the enrichment of atmospheric CO_2 (Kimble *et al*., 2002), yet carbon sequestration in agricultural soils, through the adoption of improved management practices, can mitigate this trend (Lal *et al*., 1998). Agricultural activities have profound influence on changes in soil organic carbon (SOC) both in the short and the long terms. Proper management practices that reduce C loss from agricultural soils include reduced tillage intensity, a reduction in the bare fallow period, and those that enhance inputs of crop residues, such as rotations, winter cover crops, and water management (Lal *et al*., 1998; Paustian *et al*., 2000; West and Post, 2002; Lal, 2004; Post *et al*., 2004). Carbon sequestration in agricultural soils is also accountable under Article 3.4 of the Kyoto Protocol (DEFRA, 2002). By the adoption of recommended management practices, agriculture contributes not only to soil conservation and water quality goals but also for enhancing the amount of soil organic carbon (SOC) in the soil and to mitigating carbon dioxide (CO_2) emission effects on climate change (Follett, 2001). Optimum levels of SOM can be managed through crop rotation, fertility maintenance, including use of inorganic fertilizers and organic manures, tillage methods, and other cropping system components (Huggins *et al*., 1995). Management of soils to increase soil organic carbon (SOC) levels can, therefore, increase the productivity and sustainability of agricultural systems (Cole *et al*., 1997). The study was done by Pan *et al*., 2009 suggested that enhancing carbon sequestration in croplands enhances crop productivity and stabilize yield, which offers a sound basis for GHGs mitigation. In the agricultural land plant cover is usually removed every year, so carbon sequestration means an increased carbon content of the soil (Paustian *et al*., 1998; Foereid *et al*., 2004). It is, therefore, of interest to adopt agricultural practices that sequester carbon as soil organic matter (SOM) in agricultural soils. Therefore present study was aimed to assess a comparison between bamboo plantation systems and a managed agricultural system having crop rotation and No-Till practices.

2. Materials and methods

The details of the materials used and the methods followed in carrying out the field sampling and laboratory analysis studies have been described as follows:

2.1 Description of the Experimental Study Sites

The field study was conducted in two different sites in the Tarai region of Uttarakhand namely Agroforestry Research Centre (AFRC), Haldi, Pantnagar; and Norman E. Borlaug Crop Research Centre, Pantnagar. Pantnagar is located at 29^0N Latitude, 79^03'E Longitude and at an altitude of 243.84 meters above the mean sea level. Agroforestry Research Centre (AFRC) was chosen for the study on Bamboo plantations in which two species of bamboo were taken- *B. balcooa* and *B. nutans*. The year of plantation was March 2006 in a 4.0 ha (2.0 ha each) area. The experiment was designed as CRBD block planting at 5 × 5 meter spacing. The Second study site was Norman E. Borlaug Crop Research Centre, Pantnagar where two fields were chosen for carbon sequestration study, C_{12} and D_7 having total area of 4.0 ha (2.0 ha each field). Each field was having crop rotations during the study. Crops grown in both the fields were Wheat (*Triticum aestivum*), Lentil (*Lens culinaris*), Pigeon Pea (*Cajanus cajan*), Maize (*Zea mays*), Black Gram (*Phaseolus mungo*), and Green Gram (*Vigna radiata*). The further details of the study sites are given in Table 1.

2.2 Experiment

2.2.1 Soil respiration analysis

Soil respiration in the samples collected from all four sites was measured regularly following the alkali absorption technique (Witkamp, 1961). For this, fresh soil of 500g was placed in a glass container (2L 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.

Table 1. Characteristics of the study sites.

S. no.	System	Area (ha)	Tree Density (Stem ha^{-1})	Age (Year)	Bulk density of soil (g cm^{-3})	Water holding capacity (%)
1	***B. balcooa*** **(Plantation)**	2.0	400	5	1.52	85.05
2.	***B. nutans*** **(Plantation)**	2.0	400	5	1.48	81.41
3.	**C_{12} (Agricultural system)**	2.0	-	-	1.39	60.66
4.	**D_7 (Agricultural system)**	2.0	-	-	1.38	62.08

2.2.2 Biomass determination

Biomass of bamboo was determined by destructive method by harvesting randomly selected culms of different sizes. Depending on the culm sizes 7 (seven) different girth classes each for *B. balcooa* and *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 sub-sample of each component was oven dried at 70^0C to a constant weight to calculate the dry matter of each component. For agricultural system, aboveground biomass of different crops was estimated by using 1m × 1m quadrates. All the crop plants occurring within the border of the quadrate were cut at ground level. Samples were taken to laboratory and were oven dried at 65^0C to a constant weight. Using fresh/dry weight ratio, the dry weight of crop biomass was estimated. For belowground biomass, root samples were collected with the help of core sampler of 50mm diameter and 15cm length. Samples were taken in four directions, i.e. east, west, south and north, crossing each other at the root collar. Along each line, samples were taken at a horizontal distance of 1, 2, 3 and 4m from the center up to a depth of 60cm (four cores). Thus, independent of size of each plant, four core samples were taken for each crop. Roots were hand sorted from the soil cores by mean of dry sieving and were visually inspected to remove the roots of other species. Fresh weight of all the roots was taken using a digital balance. The roots and soil from core were placed in the bag to the laboratory and oven dried at 65^0C to a constant weight. The average biomass from all core samples was then converted to biomass per crop by calculating the area occupied by the crop. In all the bamboo species, biomass in the belowground component were assumed to be the 26% of above ground biomass (Singh *et al.*, 2006).

2.2.3 Litter decomposition study

The plant litter was collected periodically from the field and was air dried first to store in the laboratory for further chemical analysis. The collected litter was homogenized to separate the plant leaf litter, which is oven dried to get the constant weight. The leaf litter was filled in the nylon meshes of size 25 x 25cm^2 for each plantation separately. The formed litter bags were placed in the field from where the litter was collected for decomposition study. Three bags were collected at monthly interval and brought into the laboratory. The bags were weighed to determine weight loss and then stored in refrigerator at 4^0C for further chemical analysis.

2.2.4 Carbon concentration in crop plants and bamboo plantations

Carbon concentration was determined by combustion method. Oven dried samples were grinded in Willey mill. 20g of the powdered sample was taken in silica crucible. The powder material was then combusted in a muffle furnace at 600°C for 4-5 hours for ashing. Carbon was assumed to constitute 50 percent of ash free dry mass (Gallardo and Merino, 1993).

2.2.5 Above and belowground biomass carbon stock/ Plant Carbon Stock

The carbon was determined using an ash content method (Gallardo and Merino, 1993). 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. Sub-samples 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 (%). Carbon stock in different plant components in agricultural system was obtained by multiplying the dry weight of different plant components by their average carbon concentration. The carbon stock obtained in different plant components was then summed up to obtain total carbon stock in agricultural crops.

2.2.6 Soil organic carbon stock and total carbon (plant + soil) stock

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} (Sa *et al.*, 2001). The plant carbon stock was estimated by multiplying total plant biomass (ton ha^{-1}) with carbon concentration (%). 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.

2.2.7 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 and Discussions

3.1 Soil respiration due to microbial activity

At *B. balcooa* plantation site, soil respiration values ranged from 821.59 to 1511.55mg CO_2 m^{-2} hr^{-1} during the whole study period of two years. The minimum values were observed in the month of December 2011 for the surface and subsurface layers. However, the activity found to be increased in the next year due to increased amount of leaf litter and improvement in soil organic carbon content. Maximum values were observed in the month of August 2012 and July 2013. For *B. nutans* the value ranged from 769.56 to 1512.84mg CO_2 m^{-2} hr^{-1} during the study. Likewise, the minimum values were observed in the month of January 2012 and maximum in the month of August 2012 and September 2012. At the C_{12} study site value varied from 621.59 to 1335.64mg CO_2 m^{-2} hr^{-1} during the study. Minimum value was observed in the month of February 2012 for surface and subsurface layer. Maximum values were observed in the month of August 2012 and July 2013. The temperature and soil moisture were found to be the main factors influencing soil respiration of the site. However, the study site D_7 showed the variation of soil respiration similar to above three study sites. Fig. 1 shows a changing pattern in the level of Soil respiration in all the study with proceeding time. The graph shows a significant difference in soil respiration activity in all study sites between both depths. At the surface layer, there was a noticeable increase in soil respiration in the second year in all sites. The overall level of soil respiration was increased in all study sites during the second year. Among all study sites, *B. balcooa* showed highest soil respiration activity in second year at the surface layer, whereas lowest rate was seen in D_7 at subsurface layer. The soil respiration is the direct function of microbial populations and carbon availability in the soil (Myrold, 1987). In rainy season the microbial population increase was observed in the present study at all the sites and similarly in the soil respiration activity. 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.

Upadhyay (2007) found marked seasonal fluctuation in the soil respiration activity of the soils in bamboo plantations similar to the present study. Overall the subsurface layer showed lesser soil respiration activity as compared to the surface layer in all the study sites in each month (Shrestha *et al.*, 2008). 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). The surface layer of the study sites are richer in carbon and nitrogen content in comparison to the subsurface layer thus higher values of soil respiration were observed in the surface layer in all the sites.

3.2 Development of regression equation in bamboo

The culms of the selected diameter class were harvested to calculate the biomass of that culm and the regression equations were developed between the biomass and the diameter of the *B. balcooa* and *B. nutans* culm. The equations thus obtained are as follows:

B. balcooa:

$$Y = 1.264\,x - 8.930;\ R^2 = 0.952^{**}$$

Where, Y= biomass of the culm (Kg) and x = diameter (cm).

B. nutans:

$$Y = 1.254\,x - 7.375;\ R^2 = 0.901^{**}$$

Where, Y= biomass of the culm (Kg) and x = diameter (cm).

As evident from R^2 values in the equations the relationships between biomass and the diameter of culm were found quite satisfactory and highly significant ($P<0.01$). Therefore, the regression equations thus developed can further be used for computing the biomass of the whole *B. balcooa* and *B. nutans* plantations. The regression technique is the most suitable technique for the calculation of biomass and carbon storage when felling of trees is not possible due to planning and prediction purposes (Jha, 2000). A Linear regression equation was developed for *D. strictus* plantations by Singh *et al.*, (2006) and Upadhyay (2007) on the basis of diameter and height measurements and similar results were observed.

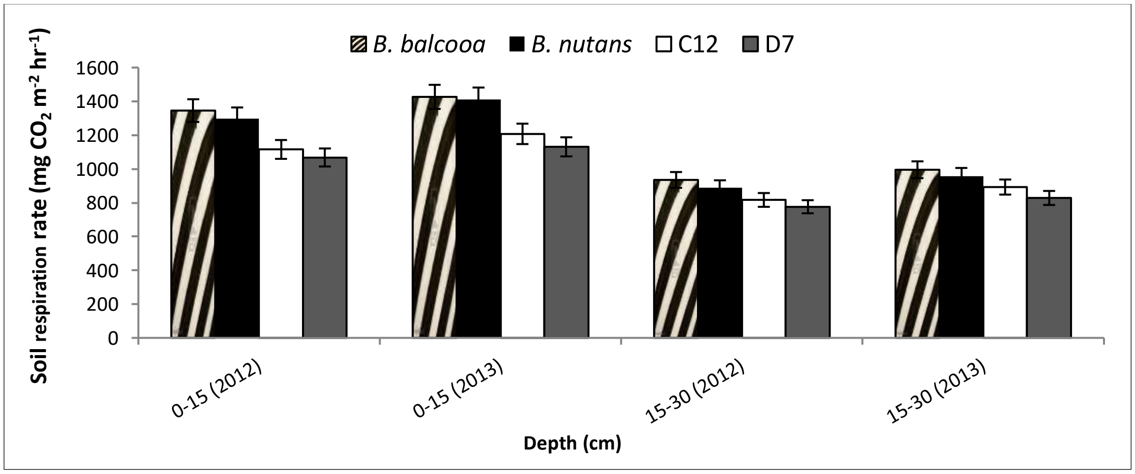


Fig. 1. Variation in Soil respiration in all study sites with depth and time.

Table 2. Above and below ground biomass (t ha^{-1}) in Bamboo plantations.

Plantation	Clump (t ha^{-1})		Litter (t ha^{-1})		Below ground (t ha^{-1})		Total (t ha^{-1})	
	2012	2013	2012	2013	2012	2013	2012	2013
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

3.3 Biomass production in bamboo plantation systems

The biomass of different plant components were found to be increased with the age of each plantation (Table 2). Hence, higher biomass were observed in the second year of the study. The total biomass was higher in the *B. balcooa* than *B. nutans* in the first and second year of study. Upadhyay (2007) observed similar results on the bamboo plantations. The biomass allocation of plantations depends upon a number of factors, *viz*., growth, habitat of the species, soil quality, soil on which bamboos are growing, age of bamboo, management practices and interaction with below ground vegetation. The above ground and below ground biomass production was 74% and 26% respectively. The culm part of the plantation or the above ground biomass contributes more towards the total biomass of the clump than the rhizome or the belowground portion (Shanmughavel *et al.*, 2001).

3.4 Litter decomposition

The time series data on weight loss of litter material filled in prepaid litter bags has been used to determine the pattern of decomposition along with changes in nutrient content the data on litter decomposition estimated in terms of percent weight loss (%) is shown in figure 2(a), and 2(b) for *B. balcooa,* and *B. nutans* respectively. The result showed that the decomposition of both the bamboo species occurred quickly and complete decomposition was observed in ten months. This may be due to the substrate quality, thus reflecting quick activity of microbes to decompose the leaf litter after colonization. Substrate quality influences the rate of decomposition of most of the species (Das and Chaturvedi, 2003). The remaining weight (%) of the leaf litter decreased with the progressing time in all the four species under observation. Similarly, the cumulative weight loss increased with the time elapsed. The highest rate of disappearance in the case of bamboo species can be attributed mainly due to the soft cuticle, low lignin content, high water soluble content and high moisture content of soil and suitable temperature (Deka and Mishra, 1982; Upadhyay, 2007). It was assumed that the weight loss of litter bags over a period of time was occurring as a constant fraction weight loss from the material (Anderson, 1973). To assess the temporal pattern of decomposition, the time series data on percent weight loss of two species was used in regression analysis. Thus the functions of the system can be formalized in the form of a regression equation.

Regression equations developed between weight loss and time are as follows [Figs. 2(a) and 2(b)].

$$\mathbf{Y = -5.535X_1 + 50.15;\ R^2 = 0.966^{ns}}$$
$$\mathbf{Y = -5.3283X_2 + 51.05;\ R^2 = 0.983^{ns}}$$

Where, Y = loss in weight (%) and X_1, and X_2 are the time factors for *B. balcooa,* and *B. nutans* respectively.

The correlation between weight loss and time factor was non-significant, but its positive value for all plantation species were signified direct relationship between weight loss and time factor. The results are quite comparable to the study of Arunachalam *et al.,* (2005) and Upadhyay (2007) on the bamboo species. They found the positive relation of weight loss rates of bamboo leaves with an incubation period of decomposition study.

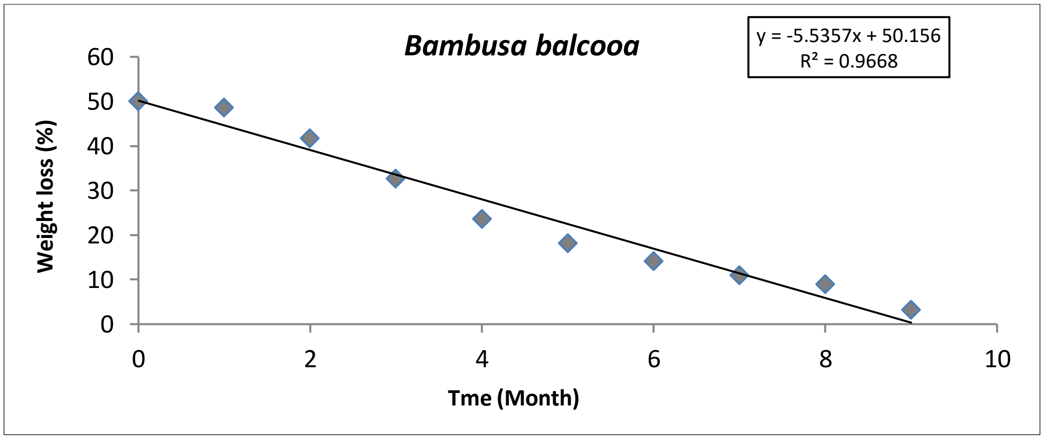


Fig. 2(a). Percent weight loss (y) in litter of *B. balcooa* expressed as a function of time (x). (The value of R^2 for regression y = bx + a, is given for the relationship).

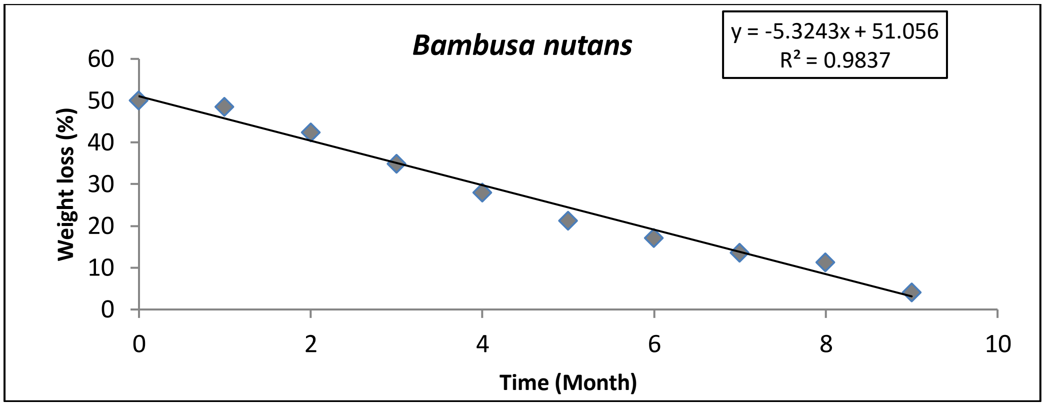


Fig. 2(b). Percent weight loss (y) in litter of *B. nutans* expressed as a function of time (x). (The value of R^2 for regression y = bx + a, is given for the relationship).

3.5 Carbon concentration and biomass carbon stock in the bamboo plantations

The values of carbon concentration in the culm were observed to be 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 32.4% for *B. balcooa* and 28.6% for *B. nutans* leaf litter. The values of the biomass carbon stock of different components of bamboo plantations are presented in Table 3. All the three parts of the Biomass Carbon Stock (Aboveground biomass + Culm + Litter) were found to be higher in *B. balcooa* as compared to *B. nutans* during the study. 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). Thus the major portion of plant photosynthesis is accumulated to the above ground parts. 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).

3.6 Carbon sequestration in bamboo plantation systems

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}. The Carbon sequestration in bamboo plantation systems is presented in Table 4. The Carbon sequestration in *B. balcooa* was found to be higher (73.38 t ha^{-1} yr^{-1}) than *B. nutans* (62.41 t ha^{-1} yr^{-1}) plantations during the study. The consistent increase in plant carbon stock might result from the increase in culm density (Nath *et al*., 2011).

3.7 Above and below ground biomass in the agricultural crops at the time of harvesting

The variation was observed in biomass production in above and below ground parts of various crops at the time of harvesting. Aboveground biomass was mainly crop biomass/straw yield (economic yield was not included) which further could incorporate into the soil and could add plant carbon into the soil. A similar study of crops was done by Sainju *et al.*, 2007. In a study done by Kundu *et al*., (2007) above and below ground crop biomass was calculated to find out net carbon input from the plant into the soil. In Table 5, the above and belowground biomass of all the crops is given. The boxes left blank show that the crop given was not sown in that field at that time. On the basis of the table, it can be observed that in C_{12} there were three crops grown during the first year of study and same were in the case of D_7. But during second year, only one crop (i.e. Wheat) were grown in C_{12}. In D_7 two crops were grown. Blank boxes show no-till period.

Crop biomass were calculated in order to find out net carbon input from plants into the soil per year, although it's totally dependent on the management practice of crop residues, whether these are burnt or used as mulch on the soil surface (Kundu *et al*., 2007). If we could use the whole straw yield as mulch, then the decomposed plant matter would surely add carbon to the soil in the form of organic matter. A similar study on carbon input from the crops into the soil was done by Kundu *et al*., (1997); Yadvinder-Singh *et al*., (1995) and Kundu *et al*., (2007). In the present study, Maize produced highest biomass, so its crop residue was higher than other crops which further incorporated into the soil and added more carbon (Eghball *et al*., 1994). Most of the crops having higher aboveground biomass were also had higher belowground biomass. Generally, the higher the aboveground yield, the higher the root biomass and exudation because crop yield positively correlates with below ground biomass (Yang *et al*., 2007).

3.8 Above and belowground carbon concentration (%), Total Nitrogen (%) and C/N ratio of crops

Above and below ground carbon concentration, total nitrogen and C/N ratio for all the six crops grown in both the agricultural fields was calculated and is presented in Table 6.

Table 3. Above and below ground biomass carbon stock (t ha^{-1}) in bamboo plantations.

Plantation	Clump (t ha^{-1})		Litter (t ha^{-1})		Below ground (t ha^{-1})		Total (t ha^{-1})	
	2012	2013	2012	2013	2012	2013	2012	2013
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. Carbon sequestration in bamboo plantations (t ha^{-1} yr^{-1}).

Plantation	Total plant carbon stock (t ha^{-1}) of year 2012	Total plant carbon stock (t ha^{-1}) of year 2013	Carbon sequestration (t ha^{-1} yr^{-1})
B. balcooa	158.46	233.84	73.38
B. nutans	97.51	159.92	62.41

Table 5. Above and below ground biomass (t ha^{-1}) in different crops at the time of harvesting.

Study site with year	Type of biomass	Crop biomass (t ha^{-1})					
		Maize	Lentil	Wheat	Black gram	Pigeon Pea	Green Gram
C_{12} (Jul, 11-Jul, 12)	AGB	6.53	2.90	-	-	-	1.71
	BGB	0.90	0.06	-	-	-	0.09
C_{12} (Aug, 12-Jul, 13)	AGB	-	-	5.68	-	-	-
	BGB	-	-	0.30	-	-	-
D_7 (Jul, 11-Jul, 12)	AGB	-	-	5.40	-	3.82	1.82
	BGB	-	-	0.28	-	0.85	0.09
D_7 (Aug, 12-Jul, 13)	AGB	-	3.12	-	1.21	-	-
	BGB	-	0.08	-	0.08	-	-

Table 6. Above and below ground carbon concentration (%), Total Nitrogen (%) and C/N ratio of crops.

Crops	Carbon concentration		Total Nitrogen		C/N ratio	
	Aboveground	Belowground	Aboveground	Belowground	Aboveground	Belowground
Maize	45.30	35.80	2.50	0.89	18.12	40.22
Lentil	44.10	38.70	1.80	0.80	24.50	48.37
Wheat	43.70	44.00	1.20	0.60	36.40	73.33
Black gram	45.50	40.70	1.90	0.70	23.94	58.12
Pigeon Pea	40.50	41.20	2.10	0.90	19.20	45.78
Green Gram	39.20	30.10	1.80	0.60	21.70	50.16

Table 7. Above and below ground biomass carbon stock (t ha^{-1}) in different crops at the time of harvesting.

Study site with year	Type of biomass	Crop biomass carbon stock (t ha^{-1})					
		Maize	Lentil	Wheat	Black gram	Pigeon Pea	Green Gram
C_{12} (Jul, 11-Jul, 12)	AGB	2.96	1.28	-	-	-	0.67
	BGB	0.32	0.02	-	-	-	0.03
C_{12} (Aug, 12-Jul, 13)	AGB	-	-	2.48	-	-	-
	BGB	-	-	0.13	-	-	-
D_7 (Jul, 11-Jul, 12)	AGB	-	-	2.36	-	1.55	0.71
	BGB	-	-	0.12	-	0.35	0.03
D_7 (Aug, 12-Jul, 13)	AGB	-	1.37	-	0.55	-	-
	BGB	-	0.03	-	0.03	-	-

The table reflects that aboveground and belowground C/N ratio was found minimum in case of Maize (18.12% and 40.22%, respectively), and maximum in case of Wheat (36.40% and 73.33% respectively). Results show that C/N ratio was found more in the roots than shoots. Due to higher C/N ratio, roots are comparatively harder to decompose than shoots (Kou *et al.*, 2012; Shah *et al.*, 2003). As reported by some researchers, a crop having a high C/N ratio can supply more organic materials with a slower decomposition rate into the soil than the crop having a lower C/N ratio (Eghball *et al.*, 1994; Robinson *et al.*, 1996; Bordovsky *et al.*, 1999).

3.9 Above and below ground biomass carbon stock in crops

Total above and below ground biomass carbon stock of all the crops at the time of harvesting is given in Table 7. Highest aboveground biomass carbon stock was observed in Maize (2.96 t ha^{-1}) whereas lowest was observed in Black gram (0.55 t ha^{-1}). In a similar way, highest below ground biomass carbon stock was observed in Pigeon Pea (0.35 t ha^{-1}) whereas lowest was observed in Lentil (0.02 t ha^{-1}).

According to Rees *et al.*, (2001), increasing the proportion of primary production returned to, or retained by the soil (e.g. crop residue retention and placement) enhances soil aggregation and influences carbon inputs in the soil. The fields were treated as fallow during the gap between harvesting of one crop and sowing of another crop. The fallow period is a time of high microbial activity and decomposition of organic matter with no input of crop residue (Halvorson *et al.,* 2002). Due to this, rapid decomposition of residue takes place which helps the residue to decompose into the soil and add organic matter into it. But long fallow period results in a decrease in total crop biomass carbon incorporated into the soil. Therefore, during the second year, above ground and below ground biomass carbon stock in crops was decreased due to minimum or no crop on fields. Therefore, intensive cropping with crop rotations helps in increasing residue carbon input into the soil as compared to crop-fallow system (Sainju *et al*., 2006). The average annual total C input to the soil from crops varied with above ground yield responses of all crops under different fertilizer application (Kundu *et al*., 2007). Crop residue management is an important component of the carbon budget of agroecosystems. After grain harvest, crop residue (straw) can be left on the surface as mulch (conservation tillage or no-till). If returned to the soil, crop residue is a direct C input to the soil, and an indirect source of mineral N through net N mineralization as the crop residue decomposes (Sandretto, 1997; Kundu *et al*., 1997). There is a strong positive relationship between the amount of C incorporated into soil, either from crop residues or from external sources such as manure, and total SOC content (Paustian *et al*., 1992; Havlin *et al*., 1990). The proportion of mean harvestable above-round biomass as carbon input from different crops is different for every crop, e.g. for soybean and wheat, it was 29 and 24%, respectively (Kundu *et al*., 2007). But in the present study total biomass carbon stock is assumed to be as carbon input into the soil and it is just compared with the gross carbon stock of bamboo plantations. It is assumed here that if this amount of carbon is assimilated by the soil, then it will enhance the level of soil carbon.

3.10 Total biomass carbon stock (aboveground + belowground)/ Plant stock in agricultural fields

It was observed that the total biomass carbon stock was higher during the first year of study than second year in both the sites (Table 8). C_{12} was having maximum plant carbon stock during the first year (5.28 t ha^{-1}) but it was decreased during the second year (2.61 t ha^{-1}). In case of D_7, plant carbon stock during first year was found 5.12 t ha^{-1} but it was decreased during the second year (1.98 t ha^{-1}).

Table 8. Total biomass carbon stock (t ha^{-1}) in both agricultural fields.

Agricultural sites	Total biomass carbon stock (t ha^{-1})	
	2010	2011
C_{12}	5.28	2.61
D_7	5.12	1.98

3.11 Total Carbon Stock (Plant + Soil) and Carbon Sequestration in bamboo plantations and Agricultural system

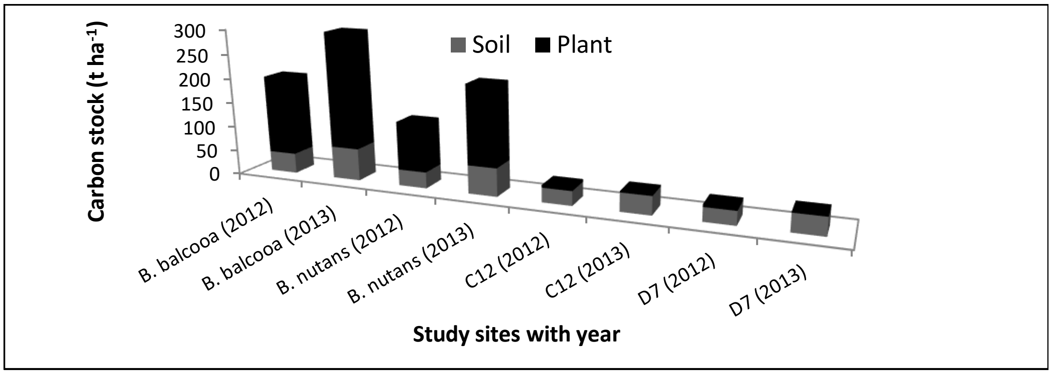
Total carbon stock (Plant Stock + SOC Stock) for both the years is given in table 9 for all study sites.

Comparative assessment of total carbon stock of all the sites reveals that bamboo plantations were having higher total carbon stock and carbon sequestration potential as compared to agricultural fields due to higher productivity, higher biomass, better soil health, higher litter biomass and best management practice. Although the agricultural system has shown better results under crop rotation practices as many studies have shown (Kundu *et al*., 2007; Kundu *et al*., 1997). The total carbon stock in agricultural system also included crop residue input into the soil and in this way it enhanced total carbon stock in agricultural systems. According to Rasmussen and Parton (1994) and Rudrappa *et al*., (2005) the change in soil carbon stock is directly related to the C input from crop residues and organic amendments. Enhanced C sequestration in agricultural soils not only has the potential to help reduce atmospheric CO_2 concentrations (Sperow *et al*., 2003) but also promotes the productivity and sustainability of agricultural systems (Lal, 2004). Figure 3 shows the variation in total carbon stocks (plant + soil) in bamboo plantations and agricultural sites with time. It is the main outcome of this study which shows a comparison between both types of ecosystems in terms of carbon pool. This comparison shows that total carbon stock was found highest in *B. balcooa* in the second year of study and the lowest was found in D_7 during the first year of study, although the difference between D_7 and C_{12} is not of much significance. The figure also shows that in bamboo plantations more carbon was locked in plant biomass whereas in agricultural system soil carbon stock was more important.

Table 9. Total carbon stock (Plant + Soil) (t ha^{-1}) and carbon sequestration (t ha^{-1} yr^{-1}) in Bamboo plantations and agricultural system.

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})
	2012	2013	2012	2013	2012	2013	
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
C_{12}	29.27	37.48	5.28	2.61	34.55	40.09	5.54
D_7	27.94	36.32	5.12	1.98	33.06	38.30	5.24

Fig. 3. Variation in total carbon stocks (Plant + Soil) in bamboo plantations and agricultural sites with time.



4. Conclusion

The biological transformation capacity of green plants has come in front as an option for secure storage of carbon build up in the atmosphere. Hence, there is a need to quantify carbon pool in plantation crops and the effect of time series data on carbon pool. Increasing the potential for agricultural soils to sequester C requires a thorough understanding of the underlying processes and mechanisms controlling soil C levels, for which a great deal of knowledge already exists. Sequestration of soil organic C from plant biomass is a key sequestration pathway in agriculture; offering an offset strategy (i.e., mitigation) for agriculture's other greenhouse gas emissions. A full-system cost-to-benefit ratio of soil C sequestration from various conservation and agricultural practices has not been adequately addressed, but is needed to fully appreciate this important pathway. Conservation agricultural systems promote soil C sequestration by tipping the balance in favor of C inputs relative to C outputs. Carbon sequestration can be achieved by maximizing C inputs and minimizing C outputs. Bamboo plantation due to rapid growth, multiplicity and having huge biomass is gaining wide popularity and attention across the globe. Therefore, its use as a carbon sequestering substrate is a good option as it has multiple benefits for the world and its people. In the present study, the higher soil organic carbon stock was observed in bamboo plantations than agricultural system. Carbon sequestration potential in the soil of bamboo plantations was higher than the agricultural system. On the basis of the results obtained in the present investigation, it may be concluded that choice of species for plantation influences carbon storage, CO_2 mitigation potential and soil properties of the plantation ecosystem. Although, the present study was mainly focused towards a comparative assessment of carbon sequestration potential of bamboo plantation and agricultural system, but it also throws light on the capacity of carbon sequestration in each site individually too. We must notice here that bamboo, being an economic plus point provides a huge hope for carbon market as it has tremendous capacity to sequester carbon due to fast growth and high primary productivity, but we cannot ignore the role of agriculture in this respect due to its rich soil carbon stock. Agriculture may not compete with forestry or agroforestry system based on its high carbon sequestration capacity, but it can enroll itself significantly in this field if some better management practices can be involved. If the straw part of the crops gets fully incorporated into the soil as mulch, it can significantly contribute to the carbon stock of the system. The study also concluded that by some effective management practices like crop rotation, no-till, and straw incorporation into the soil, carbon sequestration capacity of agriculture is positively-affected.

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