Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 9, No. 6, p. 97-112, 2016
http://www.innspub.net

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RESEARCH PAPER | OPEN ACCESS

Carbon stock assessment of bamboo plantations in Northern Mindanao, Philippines

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Article published on December 30, 2016

Key words: Climate change, Mitigation, Carbon stock, Bamboo.

Abstract

Mitigating the impacts of climate change has been a global effort of the century. Studies show the potential of bamboo as carbon sink which helps lowering the risks of climate change. This paper conducted a research study on carbon stock assessment of the three bamboo plantations located at Claveria, Misamis Oriental, Malaybalay City and Maramag Bukidnon with the following species *Dendrocalamus asper, Bambusa philippinensis and Schizostachyum lumampao,* respectively. Destructive method was conducted for the estimation of aboveground biomass (culms, twigs and leaves) and for its carbon stored. For the aboveground biomass *D. asper* obtained the highest (264.37 ton/ha) followed by *B. philippinensis* (48.29 ton/ha) and *S. lumampao* (34.49 ton/ha). The mean organic carbon content of the aboveground biomass was determined which had a range value from 52.09-54.24%. The data revealed that culms comprised the highest aboveground carbon yield (64.06-84.37%). Generally, the total carbon stock of *D. asper* (234.46 ton/ha) was higher compared to *B. philippinensis* (149.87 ton/ha) and *S. lumampao* (63.55 ton/ha). *D. asper* obtained the highest carbon stock in the aboveground (143.39 ton C/ha) which was 61.16% of the total, followed by soil (57.52 ton C/ha) 24.53% and belowground (33.55 ton C/ha) 14.31%. While both the *B. philippinensis* and *S. lumapao,* the carbon stored in soil yielded the highest percentage which were (118.19 ton C/ha) 78.86% and (41.22 ton C/ha) 64.86% respectively, followed by aboveground (17.05-28.26%) and lastly, belowground (4.09-6.89%). In these findings, it was *D. asper* showed a greater capacity to store more carbon, hence a good mitigation strategy for global warming.

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Introduction

Climate change is among the most challenging environmental, economic and social issue worldwide (Chavan and Rasal, 2010). Climate change on the planet is mainly due to the increase in the concentration of greenhouse gases (GHG) in the atmosphere. Large proportion of these emissions is attributed to anthropogenic activities associated with land use change, deforestation, fossil fuels use, inadequate agricultural practices and extensive cattle-raising (IPCC, 2008). Global warming, which has been associated with an unprecedented increase in atmospheric greenhouse gas concentrations, is expected to lead to negative impacts on valuable ecosystems (IPCC, 1992). One of the most prominent anthropogenic induced greenhouse gases is carbon dioxide (CO_2), contributing to more than 51% of the global warming (Bishaw *et al*., 2013). 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).

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). The inclusion of fast - growing perennial species like bamboo in farming systems can encourage farmers to avoid deforestation from nearby natural forests and the associated GHG emissions (Nath and Das, 2011).

Bamboo is a vernacular term designating plants of the taxonomic family of grasses, *Poaceae,* subfamily *Bambusoideae,* related to wheat, rye, barley, oats, rice, corn and sugar cane (Scurlock & Dayton *et al*., 2000). Bamboos are distributed all over the world, but major species richness is found in Asia Pacific (Bystriakova *et al*., 2003). Locsin (2000) added that bamboo grows almost everywhere in tropical countries like the Philippines, particularly in places close to water such as on riverbanks and by streams. Rojo (1999) reported that there are 62 bamboo species growing in the Philippines, only 21 species are endemic or native Philippine bamboos. The rest are introduced species. Studies of Nath and Das (2012); Yen *et al*. (2010); Chen *et al*. (2009) and Nath *et al*. (2009) affirmed that bamboo is one candidate species with a high potential for carbon sequestration and fixation. Bamboos can be significant sinks of atmospheric carbon (C) due to their fast growth and high productivity (Nath *et al*., 2008). 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. Bamboo has many advantages over timbers such as fast growth, high production, rapid maturation from shoot to culms and versatility (Scurlock *et al*., 2000). After culm harvest, large parts of the belowground biomass survive, preserving much of the sequestered carbon (Christanty and Kimmins *et al*., 1997). This is a distinct advantage that bamboo over trees, where, with the exception of species forming root suckers or stump sprouts, roots die after felling (Lobovikov *et al*., 2009).

Bamboo is indeed a promising agro forestry resource for carbon sequestration and climate mitigation. However, because of little awareness and information of the people about its role in the environment and its socioeconomic benefits it is sometimes valued lightly. Research about their ability to sequester CO_2 is inadequate and most are on the carbon storage capability in trees which are both essential as mitigation strategy. This study was undertaken to assess and compare the carbon stock of the three economically important Philippine bamboo species grown in the plantations of Claveria, Misamis Oriental, Malaybalay City and Maramag, Bukidnon Philippines namely *Dendrocalamus asper* (Botong), *Bambusa philippinensis* (Laak), *Schizostachyum lumampao* (Buho). The data serves as baseline information on carbon stock of the studied bamboo species that helps to weigh the potential of bamboo in addressing climate change issues and as well as the basis in policy making for the proper management of bamboo plantations in the Philippines.

The study aimed to: (1) calculate the total aboveground biomass (stem, leaves and twigs/branches) of the three bamboo species in selected plantations (2) estimate belowground biomass of bamboo roots (3) measure carbon stored in each bamboo component (4) measure the soil organic carbon stock through a composite soil samples taken from each $100m^2$ sampling plot of the three bamboo species.

Materials and methods

Location and description of the study

The sampling areas are located in selected bamboo plantations of Bukidnon, Province and Misamis Oriental, Province of Region 10. An ocular inspection and sampling of bamboo plantations were undertaken from the month of April to July 2016 in Tikala falls, Brgy. Poblacion Claveria Misamis Oriental, Brgy. Managok Malaybalay City, Bukidnon and Kiuntod, Barangay Camp 1, Maramag Bukidnon.

Claveria has a total land area of $825km^2$, the largest among the 23 towns of Misamis Oriental comprising one-third of the total land area of the province. It has geographical coordinates of 8°36' 36" North, 124°53' 41" East. The town has a generally rugged topography, characterized by gently rolling hills and mountains with cliffs and escarpments. The soil is classified as Jasaan clay, with a deep soil profile (greater than 1m) and rapid drainage. It is generally acidic (pH 3.9 to 5.2) with low cation exchange capacity, low to moderate organic matter content (1.8%). Claveria has a rainfall distribution of five or six wet months (>200 mm/month) and two or three dry months (<100 mm/month).

Rainfall patterns throughout the municipality vary with elevation, with the upper areas having a relatively greater amount of rainfall than the lower areas. The rainfall pattern strongly influences cropping patterns and land use across Claveria's landscape. Naturally the town is the only municipality of the province which has a cooler temperature ranging below 22 degrees Celsius in as much as 16 degrees Celsius and lower in the higher areas.

Malaybalay City, the capital city of Bukidnon, is in the central part of the province is situated in the central part of the province with coordinates of 8º9' north latitude and 125°8' east longitude. The total land area of the city is 96, 919 hectares that is about 13% of the total area of Bukidnon.

The average elevation of the city is 622 meters above sea level. About 60% of the city's area has above 30% slope, characterized by steep hills, mountains, and cliff-like stream side. About 25% are level, gently sloping, and undulating. The rests are rolling and hilly. About 66% of the city's soil is identified as undifferentiated mountain soil and the rest are clay. Meanwhile, Malaybalay City falls under Type 4 climate, which is characterized by the absence of a pronounced maximum rainy period and dry season.

The months of May to October are usually characterized with heavy rains while November to April is relatively drier period. The average annual temperature and precipitation in Malaybalay is 23.4°C and 2800 mm, respectively. Compared with the rest of the country, the climate in Malaybalay is relatively cooler the whole year round, and the area is not on the typhoon belt.

Maramag covers a total land area of 44, 726 hectares. It is located within the geographic coordinates of 7°41', to 7°58' North latitude and 124°47' to 125°14' East longitude. The largest area in Maramag in terms of the slope grouping is the 18-30%, which comprised 27.39% of the land area or an equivalent area of 14,297.30 hectares. The very steep hills and mountains (50% and above in slope) in Maramag occupy only 6,566.63 or 12.58% of the total land area. These areas are located mostly in the western and northern boundaries of Maramag. Fig. 1. is the location map of three sampling sites under study namely, Claveria Misamis Oriental, Malaybalay and Maramag Bukidnon.

Establishment of Sampling Sites

All sampling sites had an approximate of 0.5 to 1 ha total land area. Three bamboo plantations were sampled for the three bamboo species.

A modelled sampling design by Zemek (2009) as cited in Patricio and Dumago (2014) was followed with a little modification. Two sampling plots per bamboo plantation were laid out for a total of 6 plots. Each plot had a size of 5 x 20 m ($100m^2$) and contained a maximum of 2-3 groups of clumping bamboos as shown in Fig. 2.

Global positioning system (GPS) was used to collect data on coordinates of random sampling plots, define boundaries, and elevation were tabulated and included in sampling profile of three bamboo species (Table 1).

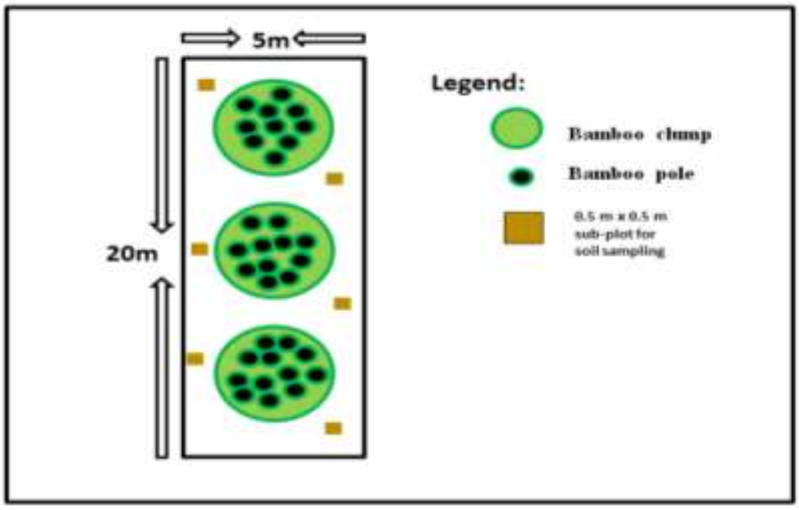

Fig. 1. 5 x 20m sampling plot.

Table 1. Sampling profile of the three bamboo species.

Bamboo Species	Plantation (area in ha)	Size of sampling plot (m^2)	Location	GPS coordinates	Elevation/Altitude
Dendrocalamus asper (Botong)	P1 (~0.5-1ha.)	2 plots of 5x20m	Tikala falls, Brgy. Poblacion Claveria Misamis Oriental	Plot 1 Longitude 124.906414˚ Latitude 8.611744˚	Plot 1 2083 ft
				Plot 2 Longitude 124.913285˚ Latitude 8.612876˚	Plot 2 2098 ft
Bambusa philippinensis (Laak)	P2 (~0.5-1ha.)	2 plots of 5x20m	Brgy. Managok Malaybalay City, Bukidnon	Plot 1 Longitude 125.204464˚ Latitude 8.027903	Plot 1 1274 ft
				Plot 2 Longitude 125.189187˚ Latitude 8.026541	Plot 2 1177 ft
Schizostachyum lumampao (Buho)	P3 (~0.5-1ha.)	2 plots of 5x20m	Kiuntod, Barangay Camp 1, Maramag Bukidnon	Plot 1 Longitude 125.020479˚ Latitude 7.711111˚	Plot1 971 ft
				Plot 2 Longitude 125.020474˚ Latitude 7.710786˚	Plot 2 948 ft

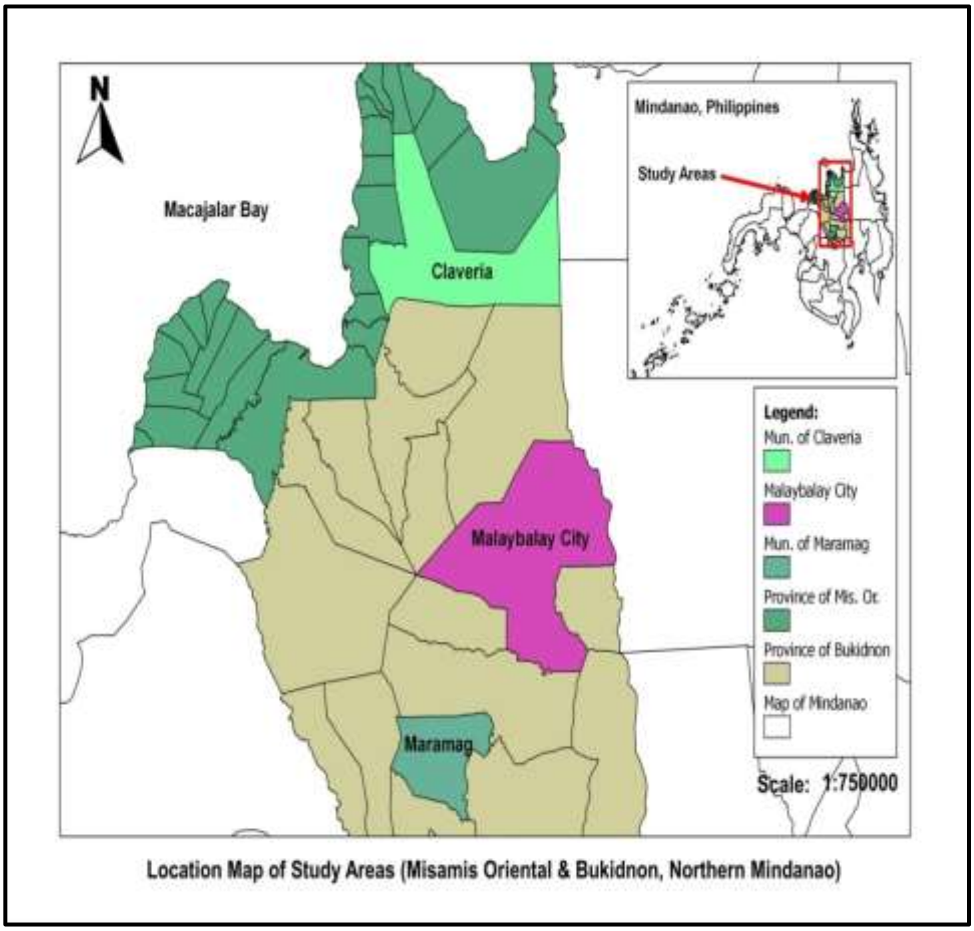

Fig. 2. Location map of the study area.

Calculation of Aboveground Biomass (AGB)

In the $100m^2$ (5 x 20 m) sampling plot, five culms in each 3 clumps of bamboo were randomly selected using simple random sampling (SRS) technique which all peripheral culms were marked in numbers and were drawn like lottery and sampled per clump. The following data were collected: a.) total number of culms per clump, b.) total height of each culm harvested using Haga altimeter and c.) diameter and thickness at breast height (1.3 m from the ground) of each culm harvested using a diameter tape or caliper.

Each sampled culm were cut and separated into stem, twigs/branches and leaves and fresh weight of stem, twigs/branches and leaves were taken. Sub samples of approximately 300g of each component were taken in the laboratory for oven dry weight and carbon analysis. Sub samples were dried in an electric oven at 80°C for 72 h until constant weight were attained.

The ratio dry weight/fresh weights were used to obtain the values of dry matter (DM) for each component of the culms. Formulas below as shown in eqn. 1 and eqn. 2, were used to get the dry weight and aboveground biomass density of each component. Total numbers of culms per hectare were obtained by manual counting. Total aboveground dry weight of the culm is the sum of the dry weight of the components:

$$\text{Component dry weight (kg/culm)} = \frac{\text{total fresh weight (kg)*subsample dry weight (g)}}{\text{subsample fresh weight (g)}} \quad \textit{eqn. 1}$$

$$\text{Aboveground biomass density (ton/ha)} = \frac{\text{Average dry weight (kg/culm)*no. of culms}}{\text{(1000) hectare}} \quad \textit{eqn. 2}$$

Calculation of Aboveground Carbon stored

For carbon content determination, 2 g of each culm components (leaves, twigs/branches and stem) were analyzed at the Soil and Plant Analysis Laboratory (SPAL) of Central Mindanao University in Musuan, Bukidnon using the Dry Ashing Method. Total carbon stock is the sum of carbon stock of all sampled components. Eqn. 3 is the formula used to get the total carbon stock in the biomass.

C stored (ton C/ha.) = Total dry weight* C content *eqn. 3*

Calculation of Belowground Carbon stored

Root biomass was not sampled destructively due to its difficulty and cost; instead, an already established method of below ground biomass estimation for bamboo species was used. In this study, below ground biomass (BGB) of each culm was estimated from the aboveground biomass (AGB) by multiplying it with a factor of 0.27 (root/shoot ratio) as shown in eqn. 4 as described by Moges *et al.* (2010) as cited in Darcha and Birhane (2015):

BGB per culm = 0.27*AGB culm^{-1} *eqn.4*

Where conversion to carbon was based on coefficient of IPCC (2006) is equal to 0.47 as shown in eqn. 5.

C (BGB) = Biomass*0.47 *eqn.5*

Soil sampling and analysis

In the 100m^2 sampling plot soil samples were obtained within a 0.5m x 0.5m subplot at 0-30 cm depth from the soil surface. Six subplots were randomly selected. Soil samples taken from 6 subplots quadrat were mixed to have a composite sample; 500 g soil sample will be taken for carbon content analysis. The soil samples were air-dried and oven dried at 105°C for 72 h. The soils were sieved through a 5-mm mesh screen to separate other components and mixed to get a uniform color and consistency. Soil samples were brought to the Soil and Plant Analysis Laboratory (SPAL) of Central Mindanao University in Musuan, Bukidnon for chemical analysis for Soil Organic Carbon (SOC) using Walkley-Black method (Mac Dicken, 1997) and for Bulk density by Oven Drying method. Bulk density was determined by collecting undisturbed soil using soil corer from Soil and Plant Analysis Laboratory (SPAL) of Central Mindanao University with a known volume of 84.52 cc. To calculate weight of Soil Organic Carbon (SOC) per hectare, the following formula was used (Patricio and Tulod 2010):

Carbon density (tonC/ha) =weight of soil *% SOC *eqn. 6*

Where:

Weight of soil (Mg)=BD (bulk density) x volume of 1 hectare

BD (g/cc)=Oven-dried weight of soil/Volume of soil core

V (volume of soil core) = 84.52 cc

Volume of 1 ha = 100m x 100m x 0.30m

Statistical analysis

The data that were gathered in this study were analysed with the use of descriptive statistics such as total, mean, percentage in comparing biomass density, biomass carbon stored and soil organic carbon stored among the three bamboo species. Analysis of variance (ANOVA) and Tukey's test were used to determine significant differences in the means of the different carbon pools in this study.

Results and discussion

Measurement data of the three bamboo species

In this study, the total number of culms sampled per bamboo species was 30 culms, followed by measuring the height, diameter and thickness. The results showed that among the three bamboo species studied *D. asper* yielded the highest mean value of height, diameter, and thickness which were 18.10m, 9.26cm, and 2.34cm, respectively (Table 2).

Roxas (2012) cited that *D. asper* can reach a range of 20-30m in height, 8-20cm in diameter and has a wall thickness of 1.1-3.6cm which was consistent with the present study. *B. philippinensis* had a smallest mean value of height and diameter which were 6.27m and 1.82cm, respectively.

However, *B. philippinensis* showed thicker wall as compared with that of *S. lumampao*. The data of *S. lumampao* acquired were again consistent to the values reported by Roxas (2012) which had range values of 10-15m tall, 4-8cm in diameter and 0.4-1cm thick.

Table 2. Measurement data of the three bamboo species.

Bamboo Species	Total number of culms sampled per bamboo species	Height of sampled culm (m)		Diameter of sampled culm (cm)		Thickness of sampled culm (cm)	
		Range	Mean	Range	Mean	Range	Mean
D. asper (Botong)	30 culms	11.5-22.3	18.10	5-12	9.26	1.9-3	2.34
B. philippinensis (Laak)	30 culms	4.4-8.9	6.27	1.4-2.3	1.82	0.9-1.6	1.21
S. lumampao (Buho)	30 culms	8.5-12.45	10.93	4-8	5.2	0.4-0.8	0.59

Aboveground biomass density of the three bamboo species

The biomass density in bamboo plantations varies between 40 and 306 ton/ha, depending on the species, climate, soil fertility, plant density and plantation age (Virtucio *et al.*, 1994; Singh and Singh, 1999; Shanmughavel *et al.*, 2001; Hunter and Junqui, 2002). Table 3 indicates that *D. asper* showed highest aboveground biomass density with a mean of 264.37ton/ha, followed by *B. philippinensis* and *S. lumampao* with mean values of 48.29 ton/ha and 34.49 ton/ha respectively.

From the above measurement data *D. asper* had the biggest sizes in height, diameter and wall thickness, these were obviously the factors which contributed to its highest biomass in the culms, twigs and leaves as compared with the two other species. Comparatively, the lower biomass value of *B. philippinensis* and *S. lumampao* could be attributed to its relatively smaller diameter and height, in contrast with *D. asper* under study. The reasons behind the difference could be attributed to the following factors such as differences in sampling site location that differ in soils, climate, and population density, age and the bamboo species itself. It was also identified that culms of bamboo yielded the highest amount of biomass of among the three species which ranged from 63.08% to 84.12% in this study, followed by twigs 11.44% to 30.11% and leaves 4.43% to 6.81%. The culm part of the plantation or the aboveground biomass contributed more towards the total biomass of the clump than the rhizome or the below ground portion (Shanmughavel *et al.*, 2001). The number of culms per hectare significantly affects the aboveground biomass density. For instance, the total number of poles for *B. philippinensis* per hectare was 8300 poles (culms) which were the highest among the three plantations. This resulted to a higher aboveground biomass density in *B. philippinensis* which was second highest next to *D. asper*. Despite that it yielded smallest dry weight per culm with a mean of 5.82kg compared with *S. lumampao* with a mean of 6.55kg. In this study, an approximate of ½ to 1 hectare of total land area of each bamboo plantations was selected. Among the three bamboo plantations, *S. lumampao* plantation had a land area of less than a hectare with fewer clumps of bamboo planted. In terms of plantation management, *S. Lumampao* plantation was not properly taken cared off by the owner and harvesting of poles was frequent as compared with the two other species. These could be the factors attributed to a lower bamboo stand density of *S. lumampao*.

Table 3. Aboveground biomass density of the three bamboo species.

Bamboo Species	Aboveground bamboo component	Average dry weight of 5 culms sampled in each component, kg		Stand density	Aboveground biomass density, ton/ha	
		Plot 1	Plot 2		Plot 1	Plot 2
D. asper (Botong)	Culm	32.18	30.46	7100	228.50	216.29
	Twigs	3.33	5.19	7100	23.64	36.87
	Leaves	1.70	1.60	7100	12.05	11.38
	Total	37.21	37.25	7100	264.19	264.55
	Species Mean	37.23		7100	264.37	
B. philippinensis	Culm	4.1	3.24	8300	34.03	26.89

Bamboo Species	Aboveground bamboo component	Average dry weight of 5 culms sampled in each component, kg		Stand density	Aboveground biomass density, ton/ha	
		Plot 1	Plot 2		Plot 1	Plot 2
(Laak)	Twigs	1.8	1.7	8300	14.97	14.11
	Leaves	0.44	0.35	8300	3.65	2.93
	Total	6.34	5.29	8300	52.65	43.93
	Species Mean	5.82		8300	48.29	
	Culm	4.88	4.94	5275	25.72	26.04
S. lumampao (Buho)	Twigs	1.41	1.11	5275	7.46	5.84
	Leaves	0.42	0.33	5275	2.20	1.72
	Total	6.71	6.38	5275	35.38	33.6
	Species Mean	6.55		5275	34.49	

The aboveground biomass density of *D. asper* falls within the range of *Bambusa bambos* in India which was 122-287 Mg/ha (Mg=ton) conducted by Shanmughavel and Franchis (1996). Recent studies of Patricio *et al.* (2014) on *D. asper* in Bukidnon, Philippines and Reyes and Ludevese (2015) in the secondary forest with Apitong stand, agroforestry and shrub/scrubland in Wahig-Inabanga Watershed, Bohol, Philippines reported the aboveground biomass density with a mean of 177.63 ton/ha, 209.51 ton/ha, 188.28 ton/ha and 172.56 ton/ha respectively, which were lower than the present study. In the same study of Patricio *et al.* (2014) the aboveground biomass density of *B. blumeana* and *B. vulgaris* with means of 97.5 ton/ha and 72.2 ton/ha, respectively were higher than *B. philippinensis* (48.29 ton/ha) and *S. lumampao* (34.49 ton/ha). Several studies of other bamboo species showed relatively closer to the result of *S. lumampao*. For example, the aboveground biomass density of *Thyrsostachys siamensis* a native bamboo in Thailand conducted by Suwannapinunt (1983), and the minimum aboveground density of *Phyllostachys heterocycla* in Sha, Fujiang, China studied by Lin (2002) yielded the following mean values of 32 ton/ha and 35.45 ton/ha, respectively.

Aboveground carbon density of the three bamboo species

In this study, it was found that aboveground carbon density of *D. asper* yielded the highest value with a mean of 143.39 ton C/ha (Table 4) which was statistically higher as compared with two other species. From the results it showed that the mean of the organic carbon content of the aboveground components (culms, twigs, leaves) among the bamboo species do not vary greatly which had a range value from 52.09% to 54.24%. This result explains that the carbon stored in each bamboo component such as those in culms, twigs and leaves among bamboo species is relatively closer among each other, which make all parts of the bamboo a package of carbon storage.

Table 4. Carbon stored in the aboveground biomass density of the three bamboo species.

Bamboo Species	Aboveground bamboo component	Aboveground biomass density, ton/ha		Mean organic carbon content, %		Aboveground carbon density, ton C/ha	
		Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
D. asper (Botong)	Culm	228.50	216.29	54.30%	54.51%	124.09	117.88
	Twigs	23.64	36.87	54.19%	54.14%	12.81	19.96
	Leaves	12.05	11.38	51.29%	51.41%	6.18	5.85
	Total	264.19	264.55	54.16%	54.32%	143.08	143.70
	Species Mean	264.37			54.24%	143.39	
B. philippinensis (Laak)	Culm	34.03	26.89	54.28%	53.11%	18.47	14.28
	Twigs	14.97	14.11	51.84%	54.15%	7.76	7.64
	Leaves	3.65	2.93	46.30%	43.69%	1.69	1.28
	Total	52.65	43.93	53.03%	52.79%	27.92	23.19
	Species Mean	48.29		52.93%		25.56	
S.lumampao (Buho)	Culm	25.72	26.04	51.91%	54.07%	13.35	14.08
	Twigs	7.46	5.84	50.54%	50.34%	3.77	2.94
	Leaves	2.20	1.72	45.46%	44.19%	1.00	0.76
	Total	35.38	33.6	51.22%	52.95%	18.12	17.79
	Species Mean		34.49		52.09%		17.96

Comparison of means for carbon stored in the culms, twigs and leaves of the three bamboo species was done using the Tukey's test (Table 5). Results showed that the bamboo components (culms, twigs and leaves) differed significantly within and between bamboo species ($p < 0.01$). For *D. asper* the following is the order of means: 120.99 ton C/ha culms > 16.39 tonC/ha twigs > 6.02 ton C/ha leaves. Similarly *B. philippinensis* shows the same order: 16.38 ton C/ha culms >7.7 ton C/ha twigs >1.49 ton C/ha leaves. This data revealed significant difference among the components of *B. Philippinensis* ($p < 0.01$). Lastly, for *S. lumampao* exhibits the following order: 13.72 ton C/ha culms >3.36 ton C/ha twigs >0.88 ton C/ha leaves. All components of *S. lumampao* varied significantly in carbon stored ($p < 0.01$). Carbon stored was more in culms (64.06%-84.37%), followed by twigs (11.43%-30.13%) and leaves (4.19%-5.81%), respectively. From the findings, it clearly shows that the culm part of bamboo contributes most of its carbon compared to twigs and leaves. This finding is consistent with the study of Nath and Das (2012) which found the culm components of bamboos stored more carbon (85%-89%) than in twigs/branches (8%-10%) and leaves (3%-4%). Furthermore, *D. asper* yielded the highest carbon stored in culms, twigs and leaves, followed by *B. philippinensis* and lastly *S. lumampao*. For culms, the following order of mean is shown: 120.99 ton C/ha for *D. asper* >16.38 ton C/ha for *B. Philippinensis* >13.72 ton C/ha for *S. lumampao*. The culms of *D. asper* varied significantly to the culms of the other two bamboo species. This could also indicate that greater DBH culms produce higher carbon stored as biomass. For twigs: 16.39 ton C/ha for *D. asper* > 7.7 ton C/ha for *B. philippinensis* > 3.36 ton C/ha for *S. lumampao*: and for leaves 6.02 ton C/ha for *D. asper* > 1.49 ton C/ha for *B. philippinensis* > 0.88 ton C/ha for *S. lumampao*. In these findings, the twigs and leaves of *D. asper* varied significantly from the twigs and leaves of the two other bamboo species ($p<0.01$). Meanwhile *B. philippinensis* and *S. lumampao* showed no significant difference between twigs and leaves ($p > 0.05$).

D. asper is comparable to the 10-15-year-old *Swietenia macrophylla* plantation located in Kapatagan, Lanao del Norte, Philippines which yielded an aboveground carbon density of 132.75 Mg C/ha (Mg=ton) conducted recently by Zaragoza *et al.* (2016). While the same study of Patricio *et al.* (2014) of *D. asper* expressed lower carbon density as compared with the present study with a mean of 86.7 ton C/ha. According to Tulod (2015) the amount of carbon stock usually varies with the amount of biomass produced; hence, the larger the biomass, the larger is the stored carbon. The lower aboveground carbon density of *B. philippinensis* and *S. lumampao* with mean values of 25.56 ton C/ha and 17.96 ton C/ha respectively, were merely due to their lower biomass densities. These two values were seemingly the lowest carbon density among bamboo species recently studied in Philippines. For instance *B. blumeana* and *B. vulgaris* studied by Patricio *et al.* (2014) showed a greater carbon density with mean values of 46.1 ton C/ha and 33.4 ton C/ha. However, in this study, the aboveground carbon density of *B. philippinensis* and *S. Lumampao* were higher when compared to *Saccharum* dominated grasslands reported by Lasco (2007) as cited in Patricio *et al.* (2014) with an aboveground carbon density value of 13.1 ton C/ha.

Table 5. Comparison of means for carbon stored in culms, twigs and leaves of the three bamboo species.

Bamboo Species	Mean aboveground carbon density, ton C/ha			Statistical analysis
	Culms	Twigs	Leaves	P-value
D. asper (Botong)	120.99^{a}	16.39^{b}	6.02^{b}	3.67E-12
B. philippinensis (Laak)	16.38^{c}	7.70^{d}	1.48^{e}	1.43E-08
S. lumampao (Buho)	13.71^{c}	3.36^{d}	0.88^{e}	1.66E-10
P-value	2.01E-12	5.51E-04	1.52E-08	

Note: *Means with the same letter superscript within a row are not significantly different from each other.

*Means with the same letter superscript within a column are not significantly different from each other.

Belowground carbon density of the three bamboo species.

Precise data in root biomass of bamboo is necessary in estimating the carbon stock in bamboo forest or plantations. However, limited studies are available on root biomass of bamboo and most of studies focus on trees. Destructive sampling in root biomass was not conducted due to difficulty, cost, lack of experts and as well the damage it may inflict upon the bamboo clumps.

Instead, in this study the root biomass/belowground biomass was obtained by getting the product of aboveground biomass (AGB) and the default factor of 0.27 (root/shoot ratio) (Moges *et al.*, 2010 as cited in Darcha and Birhane, 2015). Conversion of belowground biomass density to carbon stored was obtained by multiplying the former with a 0.47 (IPCC, 2006). Table 6 shows the belowground density of the three bamboo species with the following sequence: 71.33 ton/ha *D. asper* >13.04 ton/ha *B. philippinensis* >9.31 ton/ha *S. lumampao*.

The study of secondary forest with Apitong, agroforestry, shrub/scrubland in Wahig-Inabanga Watershed, Bohol Philippines conducted recently by Reyes and Ludevese (2015) yielded lower belowground biomass as compared to the *D. asper* with values of 38.13, 34.71 and 32.77 ton/ ha, respectively. However, these values are higher compared to the two other bamboo species in this study. Furthermore, the carbon stored in the belowground biomass of *D. asper* was 33.55 ton C/ha which was higher as compared to those of *B. philippinensis* and *S. lumampao* with mean values of 6.13 ton C/ha and 4.38 ton C/ha, respectively. *D. asper* belowground carbon density was comparable to *Bambusa balcooa* in North India which had a belowground carbon density of 33.49 ton C/ha (2010) and 49.42 ton C/ha (2011) (Tariyal *et al.*, 2013). From the abovementioned bamboo species it was clear that *D. asper* yielded the highest biomass. Consequently, both in the aboveground biomass and in the belowground biomass yielded higher carbon as compared to the other two bamboo species.

Table 6. Carbon stored in the belowground biomass density of the three bamboo species.

Bamboo Species	Aboveground biomass density, ton/ha		Belowground biomass density ton/ha (AGBD * 0.27)		Belowground carbon density Ton C/ha (BGBD * 0.47)	
	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
D. asper (Botong)	264.19	264.55	71.33	71.43	33.53	33.57
Mean	264.37		71.38		33.55	
B. philippinensis (Laak)	52.65	43.93	14.22	11.86	6.68	5.57
Mean	48.29		13.04		6.13	
S. lumampao (Buho)	35.38	33.6	9.55	9.07	4.49	4.26
Mean	34.49		9.31		4.38	

Carbon Stored in the Soil of the Three Bamboo Species

In this study, soil was taken from the soil depth of 0-30cm and the soil organic carbon in bamboo plantations was calculated based on the product of soil carbon content and bulk density on the basis of mass balance. Table 7 shows the soil organic carbon stored in the three bamboo plantations. The bulk density values of soil in all bamboo plantations were relatively closer to each other which ranged from 1.11g/cc to 1.59 g/cc. On the other hand, the mean values of organic carbon content vary greatly which ranged from 0.99% to 2.93%, which was higher as compared to the soil carbon content in bamboo agro forestry of Northeast India of 0.87-1.39% (Nath, 2008). This variation may due to the differences in output and input of organic matter present in each bamboo plantation. Nevertheless, the values of organic carbon fall within the criteria of moderate to high as classified by Herrera (2005): low (0.6-1.16%), moderate (1.16-1.74%) and high (>1.74%). In this study, *B. philippinensis* plantation yielded the highest soil organic carbon with a mean value of 118.19 ton C/ha, which falls within the range of 71.48-204.37 ton C/ha reported by Zhou and Jiang (2004) and Wang *et al.* (2009a) for *Phyllostachys praecox* bamboo stands in China. Followed by *D. asper* (57.52 ton C/ha) and lastly, *S. lumampao* (41.22 ton C/ha). The divergence of soil organic carbon could be caused by the differences in soil type, soil organic matter, bamboo species, climate, disturbance, and land use and management practice. In the present study, the soils of the three bamboo plantations were not subject to any silviculture practices and management. It is interesting to note that *B. philippinesis* of the current study yielded higher SOC compared to the *Phyllostachys praecox* with mean of 92.5 Mg C/ha (Mg=ton) under intensive management in Zhejiang, China conducted by Zhuang *et al.* (2011).

Soil organic dynamics is also affected by the change in land use (Lasco, 2002) and soil management practices, although the mechanisms and processes of carbon sequestration in soil are still not completely understood (Lal *et al.*, 1995; Bajracharya *et al.*, 1998) as cited by Bijaya (2008).

Table 7. Carbon stored in the soil of the three bamboo species**.**

Bamboo Species	Bulk density g/cc		Weight of soil ton		Mean carbon content, %		Soil organic carbon stored ton C/ha	
	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
D. asper (Botong)	1.14	1.13	3420	3390	2.67	0.7	91.31	23.73
Mean	1.135		3405		1.69		57.52	
B. philippinen-sis (Laak)	1.59	1.11	4770	3330	2.84	3.03	135.47	100.9
Mean	1.35		4050		2.93		118.19	
S. lumampao (Buho)	1.39	1.38	4170	4140	1.55	0.43	64.64	17.80
Mean	1.385		4155		0.99		41.22	

In the present study, the environment specifically the differences in the land where the plantations are situated attributed to the capacity of soil to store carbon and hence, cause variation in the carbon stored. As observed in the research site, *B. philippinensis* was dominated with litter fall which could decompose in the soil under the bamboo plantation and the soil type is sandy loam, these may contribute to high organic carbon in soil.

Hosur and Dasog (1995) also reported that due to higher litter production the organic carbon increases. The lower stand density of *S. lumampao* (5, 275 culms/ha) may contribute to the lower litter accumulation in contrast with the *B. philippinensis* (8, 300 culms/ha) which had the highest stand density. However, carbon in litter fall and soil physicochemical properties was not examined in this study. It is worthwhile to mention that the data provided may not be sufficient to account for differences in soil organic carbon in the three bamboo plantation.

The study of Tulod (2015) on *Tectona grandis* L.f. in Musuan Bukidnon, Philippines which yielded a total of 134.58 MgC/ha (Mg=ton) showed higher soil organic carbon (SOC) as compared to all the bamboo plantations in the present study. Some studies on the soil organic carbon of several bamboo species had been established. Tariyal *et al.* (2013) reported the soil organic carbon stock in the plantations of 7-yr-old *D. strictus* and *B. vulgaris* in Northeast India with values of 106.56 ton C/ha and 85.06 ton C/ha respectively, expressed lower soil organic carbon stored when compared to *B. philippenensis* but higher as compared to the two other bamboo species in this study. Sohel *et al.* (2015) also reported the soil organic carbon of the 5-yr-old *B. vulgaris* locatedat Lawachara forest reserve in Bangladesh which had a value of 24.71 ton C/ha lower than *S. lumampao*. In this study, the soil organic carbon (SOC) values in the three bamboo plantations falls within the range of Moso bamboo (*Phyllostachys pubescens*) in Anji County of South-eastern China which was 34.80-176.17 Mg/ha (Mg=ton) conducted by Fu *et al.* (2013).

Total carbon stock of the three bamboo species

In this study, total carbon stock was obtained by summing up the total aboveground carbon density, belowground carbon density, and carbon stored in soil of each bamboo species. Fig. 3 and Table 8 show that *D. asper* obtained the highest total carbon stored with a mean of 234.46 ton C/ha which is equivalent to 15.63 ton C/ha/yr of carbon sequestered per year. Followed by *B. philippinensis* (149.87 ton C/ha), and *S. lumampao* (63.55ton C/ha), respectively. The high value of carbon stored in *D. asper* was accounted mostly by aboveground carbon density (143.39 ton C/ha) which was 61.16% of the total, followed by carbon stored in soil (57.52 ton C/ha) 24.53%, and belowground carbon density (33.55 ton C/ha) 14.31%. The total carbon stock of *D. asper* was comparable to the second growth forest in Bukidnon, Philippines conducted by Tulod (2015) with 217.46 Mg C/ha (Mg=ton).

Table 8. Total carbon stock of the three bamboo species.

Bamboo Species	Aboveground carbon density, ton C/ha		Belowground carbon density, ton C/ha		Soil organic carbon, ton C/ha		Total carbon stored ton C/ha		Carbon mean annual increment, ton C/ha/yr	
	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
D. asper (Botong) 15 yrs old	143.08	143.70	33.53	33.57	91.31	23.73	267.92	201	17.86	13.40
Mean	143.39		33.55		57.52		234.46		15.63	
B. philippinensis (Laak) 15 yrs old	27.92	23.19	6.68	5.57	135.47	100.9	170.07	129.67	11.34	8.64
Mean	25.56		6.13		118.19		149.87		10.00	
S. lumampao (Buho) 20 yrs old	18.12	17.79	4.49	4.26	64.64	17.80	87.25	39.85	4.36	1.99
Mean	17.96		4.38		41.22		63.55		3.17	

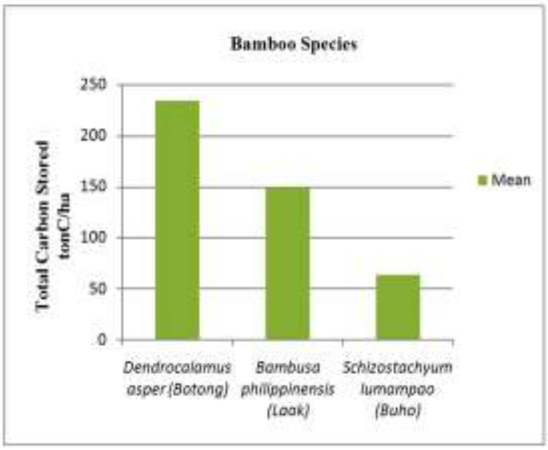

Fig. 3. Total carbon stock of the three bamboo pecies.

The second highest total carbon stock was *B. philippinensis* with a mean of 149.87 ton C/ha with an amount of 10 ton C/ha/yr of carbon sequestered per year. In this plantation, carbon stored in soil rendered the highest percentage which was 78.86% (118.19 ton C/ha) of the total carbon stored, followed by aboveground carbon density (25.56 ton C/ha) which was 17.05% and belowground carbon density with 4.09% (6.13 ton C/ha).

This was higher compared to the secondary forest with Apitong stand, agro forestry, and shrub/scrubland carbon assessment in the Wahig-Inabanga Watershed, Bohol Philippines, conducted recently by Reyes and Ludevese (2015) which yielded carbon stock of 115.22 ton C/ha, 104.05 ton C/ha and 95.90 ton C/ha, respectively. This is consistent with the study of *Phyllostachys pubescens* in Fujian, China by Zhuang *et al.* (2015) in which soil also yielded the highest carbon stored of 90.6 Mg/ha (Mg=ton) with a total of 145.3 Mg/ha.

The lowest of total carbon stock was *S. lumampao* with a mean of 63.55ton C/ha with an amount of 3.17 ton C/ha/yr of carbon sequestered per year. Similar with *B. philippinensis* the carbon stored in soil yielded the highest percentage which was 64.86% (41.22 ton C/ha) of total, followed by aboveground carbon density with 28.26% (17.96 ton C/ha) and belowground carbon density 6.89% (4.38 ton C/ha).

This result was higher compared to mangrove in Bohol, Philippines studied by Reyes and Ludevese (2015) with carbon stock of only 49.77 ton C/ha.

Table 9 shows that the aboveground and belowground carbon densities in *D. asper* were statistically different from the two other bamboo species ($p < 0.01$). In contrast, *B. philippinensis* and *S. lumamapao* revealed no significant difference with each other ($p > 0.05$). It shows that *D. Asper* is 6-8 times higher in aboveground carbon density compared to that of the other two bamboo species. This finding is similar with the belowground carbon since it was derived as a proportion of the aboveground biomass density.

Table 9. Comparison of means for carbon stored in the aboveground biomass density and belowground biomass density of the three bamboo species.

Bamboo species	Mean aboveground carbon density, ton C/ha	Mean belowground carbon density, ton C/ha
D. asper (Botong)	143.39[a]	33.55[a]
B. philippinensis (Laak)	25.56[b]	6.13[b]
S. lumampao (Buho)	17.96[b]	4.38[b]
P-value	2.46E-04	2.49E-04

Note: *Means with the same letter superscript within a column are not significantly different from each other

Conclusions and Recommendations

In this study, it was observed that the total carbon stock in both *B. philippinensis* and *S. lumampao* plantations were contributed by their soils: 118.19 ton C/ha and 41.22 ton C/ha respectively.

This finding is consistent with the study of Post *et al.* (1990) that soils stored an estimated 2.5 to 3 times as much as that stored in plants. Meanwhile, *D. asper* obtained most of its carbon accumulation from aboveground biomass production of 143.39 ton C/ha.

The reasons behind the difference of soil organic carbon content lies in the fact that each bamboo plantations is unique in terms of soil, input and output of organic materials and with their surrounding environment. Further research is needed in soil dynamics of bamboo plantations which includes litter fall, physicochemical characteristics of soil and soil organic matter are highly recommended in order to enhance the understanding about soil organic carbon (SOC). Moreover, the overall data of SOC in all bamboo plantations in this study was still satisfactory indicating good site condition. This implies that soils play an important role in mitigating global warming which considered as one of the biggest carbon pools studied.

Furthermore, no sufficient studies on soil organic carbon in other bamboo species within the Philippines are available to compare the SOC of the present study. Hence this serve as a baseline study for future studies in line with soil carbon stored in bamboo plantations. The relationship of total aboveground carbon stored to total belowground carbon stored is directly proportional, since root biomass was not sampled destructively but derived from the aboveground biomass using estimated value. The mean aboveground carbon density obtained were 143.39 ton C/ha for *D. asper*, 25.56 ton C/ha for *B. philippinensis* and 17.96 ton C/ha for *S. lumampao.*

From the result, the aboveground carbon of *D. asper* showed higher potential as carbon sink compared with the other two bamboo species. Aside from that, *D. asper* is known for its wide range of economic values such as the culms are excellent for bamboo furniture and the shoots for food source. With this, promoting bamboo plantations especially *D. asper* plantation and utilizing bamboo products would not only help in mitigating climate change but as well as supporting our farmers. Meanwhile, the belowground carbon density in this study ranged from 4.09%-14.31% of the total carbon stock.

The root and rhizome system of bamboo provides a promising carbon storage considering the fact that they would not die after harvest of the culms. Further research on other bamboo species in their carbon stock and sequestration capability are highly recommended since Philippines caters different genera of native bamboo species but no studies have yet been done.

Acknowledgement

The authors would like to thank the Department of Science and Technology (DOST) for funding the research study, to Soil and Plant Analysis Laboratory (SPAL) of Central Mindanao University in Musuan, Bukidnon for the analysis of carbon content of bamboo tissues and soil samples, to Myrna S. Decipulo for her valuable inputs during the conduct of ocular inspection activities.

References

Bijaya DGC. 2008. Carbon Sequestration Potential and Uses of *Dendrocalamus strictus*. BSc thesis. Tribhuvan University Institute of Forestry Pokhara Campus, Nepal pp. 1-46.

Bishaw B, Neufeldt H, Mowo J, Abdelkadir A, Muriuki J, Dalle G, Assefa T, Guillozet K, Kassa H, Dawson IK, Luedeling E, Mbow C. 2013. Farmers' strategies for adapting to and mitigating climate variability and change through agroforestry in Ethiopia and Kenya. In: Davis, C.M., Bernart, B. & Dmitriev, A. (Eds.). Forestry Communications Group, Oregon State University, Corvallis Oregon.

Bystriakova N, Kapos V, Lysenko I, Stapleton C. 2003. Distribution and conservation status of forest bamboo biodiversity in the Asia-Pacific region. Biodiversity and Conservation **12,** 1833-1841.

Chavan BL, Rasal GB. 2010. Sequestered standing carbon stock in selective tree species grown in University campus at Aurangabad, Maharashtra, India. International Journal of Environmental Science and Technology **2,** 3003-3007.

Chen XG, Zhang XQ, Zhang YP, Booth T, He XH. 2009. Changes of carbon storages in bamboo stands China during 100 years. Forest Ecology and Management **258,**1489-1496.

Choudhary ML. 2008. One Year of National Bamboo Mission in the states of NE Region, West Bengal, Orissa, Jharkhand & Bihar 2007-2008. Cane & Bamboo Technology Centre Guwahati, Assam India.

Christanty L, Kimmins JP, Mailly D. 1997. Without bamboo, the land dies: A conceptual model of the biogeochemical role of bamboo in an Indonesian agroforestry system. Forest Ecology and Management **91,** 83-91.

Darcha G, Birhane E. 2015. Biomass and Carbon Sequestration Potential of *Oxytenanthera abyssinica* in the Homestead Agroforestry System of Tigray, Ethiopia. Journal of Natural Sciences Research **5,** 69-77.

Fu W, Jiang P, Zhao K, Zhou G, Li Y, Wu J, Du H. 2013. The carbon storage in moso bamboo plantation and its spatial variation in Anji County of southeastern China. Journal of Soils Sediments **14,** 320-329.

Herrera E. 2005. Soil Test Interpretations. Guide A-122. College of Agriculture and Home Economics, New Mexico State University.

Hosur GC, Dasog GS. 1995. Effects of tree species on soil properties.

Hunter IR, Junqui W. 2002. Bamboo biomass. International Network of Bamboo and Rattan, 11p.

INBAR. 2006. In partnership for a better world – strategy to the year 2015. Beijing, China: INBAR p. 23.

IPCC (Intergovernmental Panel for Climate Change). 1992. The 1992 IPCC supplement scientific assessment. Working group I. Intergovernmental panel on climate change. Geneva p. 1-22.

IPCC (Intergovernmental Panel for Climate Change). 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T., Tanabe K., (Eds). Published: IGES Japan.

IPCC (Intergovernmental Panel for Climate Change). 2008. Climate change 2007. Synthesis report. Contribution of Working Groups I, II and III to the fourth assessment report. In: Pachauri, R.K., Reisinger, A. (Eds.), Intergovernmental Panel on Climate Change (IPCC), Geneva-Switzerland p.104.

Landsberg JJ, Linder S, McMurtrie RE. 1995. Effects of global change on Managed forests-A strategic plan for research on managing forest ecosystems in a globally changing environment. GCTE report no. 4. IUFR occasional paper no.1. Global Change Terrestrial Ecosystems and International Union of Forest Research Organizations p. 1-17.

Lasco RD. 2002 Forest carbon budgets in Southeast Asia following harvesting and land cover change. Science in China **45,** 55-64.

Lin H. 2002. Study on dynamic law of biomass in Bamboo *(Phyllostachys heterocycla)* Forest Ecosystem. Forest Science Technology Development **16,** 25-27.

Lobovikov M, Lou Y, Schoene D, Widenoja R. 2009. The Poor Man's Carbon Sink. Bamboo in Climate Change and Poverty Alleviation, Food and Agricultural Organization, Rome, Italy p. 72.

Locsin MEP. 2000. Bamboo. Manila: Centro Escolar University.

MacDicken KG. 1997. A guide to monitoring carbon storage in forestry and agroforestry projects. Winrock international institute for Agricultural Development. Virginia, USA p. 87.

Nath AJ, Das AK. 2011. Carbon storage and sequestration in bamboo-based small holder home gardens of Barak Valley, Assam. Current Science **100,** 229-233.

Nath AJ, Das AK. 2012. Carbon pool and sequestration potential of village bamboos in the agro-forestry system of northeast India. Tropical Ecology **53,** 287-293.

Nath AJ, Das G, Das AK. 2008. Above ground biomass, production and carbon sequestration in farmer managed village bamboo grove in Assam, northeast India. Journal American Bamboo Society **21,** 32-40.

Nath AJ, Das G, Das AK. 2009. Above ground standing biomass and carbon storage in village bamboos in north east India. Biomass and Bio-energy **33,** 1188-1196.

Nath AJ. 2008. Studies on the Ecology and Management of Bamboos in Traditional Homegardens of Barak Valley, North East India. Ph.D. Thesis, Assam University Silchar.

Pan Y, Birdsey R, Fang J, Houghton R, Kauppi P, Kurz W, Phillips O, Shvidenko A, Lewis S, Canadell J, Ciais P, Jackson R, Pacala S, Mcguire A, Piao S, Rautainen A, Sitch S, Hayes D. 2011. A large and persistent carbon sink in the world's forests. Science **333,** 988-993.

Patricio JHP, Dumago SWL. 2014. Comparing Aboveground Carbon Sequestration of Three Economically Important Bamboo Species Grown in Bukidnon. Journal of Multidisciplinary Studies **3,** 1-15.

Patricio JHP, Tulod AM. 2010. Carbon sequestration potential of Benguet Pine *(Pinus kesiya)* plantation in Bukidnon, Philippines. Journal of Nature Studies **9,** 1-7.

Post WM, Peng TH, Emanuel WR, King AW, Dale VH, Angelis DL. 1990. The Global Carbon Cycle. American Scientist **78,** 310-326.

Reyes TDJr, Ludevese EG. 2015. Rapid Carbon Stock Appraisal (RACSA) Implementation in Wahig-Inabanga Watershed, Bohol, Philippines. International Journal of Environmental and Rural Development **6,** 102-109.

Rojo J. 1999. Bamboo resources of the Philippines. In proceedings of the first national conference on bamboo. Iloilo City, Philippines p. 65-70.

Roxas CA. 2012. Handbook on Erect Bamboo Species Found in the Philippines. Ecosystems Research and Development Bureau, Department of Environment and Natural Resources, College, Laguna.

Scurlock JMO, Dayton DC, Hames B. 2000. Bamboo: an overlooked biomass resource. Biomass and Bioenergy **19,** 229- 244.

Shanmughavel P, Francis K. 1996. Aboveground biomass production and nutrient distribution in growing bamboo (*Bambusa bambos* (L.) Voss). Biomass and Bioenergy **10,** 383-391.

Shanmughavel P, Peddappaiah RS, Muthukumar T. 2001. Biomass production in an age series of Bambusa bambos plantations. Biomass and Bioenergy **20,** 113-117.

Singh AN, Singh JS. 1999. Biomass, net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region. Forest Ecology Management **119,** 195-207.

Sohel MSI, Alamgir M, Akhter S, Rahman M. 2015. Carbon storage in a bamboo (*Bambusa vulgaris*) plantation in the degraded tropical forests: Implications for policy development. Land Use Policy **49,**142-151.

Suwannapinunt W. 1983. A study on the biomass of *Thyrsostachys siamensis* (Gamble) forest at Hin-Lap, Kanchanaburi. Journal of Bamboo Research **2,** 227-237.

Tariyal K, Upadhyay A, Tewari S, Melkania U. 2013. Plant and soil carbon stock and carbon sequestration potential in four major bamboo species of North India. Journal of Advanced Laboratory Research in Biology 90-98.

Tulod AM. 2015. Carbon stocks of second growth forest and reforestation stands in Southern Philippines: baseline for carbon sequestration monitoring. Advances in Environmental Sciences - International Journal of the Bioflux Society **7,** 422-431.

Virtucio FD, Manipula BM, Schlegel FM. 1994. Culm yield and productivity of laak *(Sphaerobambos philipinensis)* In: Proceedings 4thInternational Bamboo Workshop on Bamboo in Asia and the Pacific. Chiangmai, Thailand, November 27-30, 1991. Technical Document Forspa Publication.

Wang B, Wang Y, Guo H, Zhao GD, Bai XL. 2009a. Carbon storage and spatial distribution in *Phyllostachys pubescens* forest in Dagangshan Mountain of Jiangxi Province. Journal of Beijing Forestry University **31,** 39-42.

Yen TM, Ji YJ, Lee JS. 2010. Estimating biomass production and carbon storage for a fast-growing makino bamboo (*Phyllostachys makino*) plant based on the diameter distribution model. Forest Ecology and Management **260,** 339-344.

Zaragoza MJG, Amparado RFJr, Aranico EC, Tampus AD. 2016. Carbon stock assessment of three different vegetative covers in Kapatagan, Lanao del Norte, Philippines. Advances in Environmental Sciences -International Journal of the Bioflux Society **8,** 205-220.

Zhou GM, Jiang PK. 2004. Density, storage and spatial distribution of carbon in *Phyllostachy pubescens*. Forestry Science **40,** 20-24.

Zhuang S, Ji H, Zhang H, Sun B. 2015. Carbon storage estimation of Moso bamboo (*Phyllostachys pubescens*) forest stands in Fujian, China. Tropical Ecology **56,** 383-391.

Zhuang S, Sun X, Liu G, Wong M, Cao Z. 2011. Carbon Sequestration in Bamboo Plantation Soil with Heavy Winter Organic Mulching Management. Botanical Review **77,** 252-261.