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Comparing Aboveground Carbon Sequestration of Three Economically Important Bamboo Species Grown in Bukidnon, Philippines

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Abstract

Bamboo is widely distributed in the Philippines. As a non-timber forest product with a wide-ranging economic importance, bamboo has attracted the attention of ecologists because of its versatility in terms of ecological services including carbon sequestration and its potential to mitigate climate change. This paper assessed the carbon sequestration potential of three economically important bamboo species grown in plantations in Bukidnon, Philippines. Aboveground biomass (leaves, twigs and branches, and culms) and carbon densities of plantations of *Dendrocalamus asper*, *Bambusa blumeana* and *Bambusa vulgaris* were determined. *D. asper* statistically (α=0.01) had the highest aboveground biomass density with 177.6 t ha^{-1} while *B. vulgaris* had the lowest density with 72.2 t ha^{-1}. Aboveground biomass of the three species yielded an average organic carbon content of 47.38% with *D. asper* having the highest at 48.71%. Consequently, *D. asper* statistically (α=0.01) had the highest aboveground carbon stored with an average of 86.7 tC ha^{-1}, followed by *B. blumeana* with 46.1 tC ha^{-1} and *B. vulgaris* with 33.4 tC ha^{-1}. Considering the potential of these bamboo species to store atmospheric carbon, there is a need to propose policies that strongly advocate the establishment of bamboo plantation-related projects in the country as an alternative course of action that can mitigate the impacts of global warming and climate change. Planting and managing bamboo plantations are recommended utilizing species like *D. asper* which has the potential to sequester relatively higher amount of carbon.

Keywords: biomass, climate, ecological, plantations, warming

Introduction

Climate change caused by global warming is considered to be the most pressing environmental problem mankind is facing today. The Intergovernmental Panel on Climate Change [IPCC] (2013) claimed in its latest (5th assessment) report that "each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850." From 1850-2012, combined data on land and ocean temperature showed that the earth has warmed by an average of 0.85 °C. Such extent of warming is a strong indication of the unprecedented rise in levels of carbon dioxide, methane, and nitrous oxide in the last 800,000 years. In 2011, the concentration of CO_2 was 391 ppm, which exceeded the pre-industrial levels by about forty percent.

One way to manage atmospheric carbon is through sequestration. Carbon sequestration is the elimination of carbon dioxide from the atmosphere and storing it to long-term carbon sink such as plants. One of these plants is bamboo which holds great promise because of its fast growing characteristics. Bamboo can be one of the potential species for plantation in degraded or wastelands to act as a carbon sink in the sense that it contains biomass that stores a large quantity of carbon (Maoyi, 2007).

Realizing not only the economic importance of bamboo but also its role in climate change mitigation through carbon sequestration, the government through the Department of Environment and Natural Resources (DENR) embarked on bamboo research and development project in various sites of the country including Bukidnon. The province has about 1228 ha of bamboo stands (Virtucio & Roxas, 2003) which are planted with commercially important species including *Dendrocalamus asper* (Schult. f.) Backer ex Heyne (giant bamboo), *Bambusa blumeana* Schult. f. ("kawayan tinik"), and *Bambusa vulgaris* Schrad. ex J.C. Wendl. ("kawayan kiling"). Decipulo et al. (2009) cited that approximately 87% of the area has been planted with *D. asper*, while the rest is grown with *B. blumeana*, *B. vulgaris*, *Gigantochloa levis* and other bamboo species. *D. asper* plantations were about 27 years old as they were established in 1986 while *B. blumeana* and *B. vulgaris* plantations were about 24 years old since these were established in 1989. The Center for Ecological Development and Recreation (CEDAR) of the DENR and the local government units of Impasugong and Malaybalay City co-manage these bamboo plantations.

The growing interest in forest plantation species like bamboo in increasing carbon sinks as a mitigation strategy can be attributed to its inexpensiveness, high carbon uptake potential, and associated socioeconomic and environmental benefits. Given this background, it is important therefore to generate a pool of reliable information on carbon sequestration ability of *D. asper*, *B. blumeana*, and *B. vulgaris* that will serve as the basis for more effective interventions in managing and developing bamboo plantations. Hence, this paper is a synthesis of the potential of the above-mentioned bamboo species to sequester atmospheric carbon.

Materials and Methods

Locale of the study

The study site for *D. asper* plantation was situated in Impasugong while *B. blumeana*, and *B. vulgaris* plantations were in Malaybalay City, both in Bukidnon Province, Philippines (Figure 1). Impasugong is strategically located in the northeastern part of Bukidnon Province with geographical coordinates of $8^0$7’ to $8^0$35’ north latitude and $124^0$18’ to $125^0$18’ east longitude. Almost 60% of the municipality has an elevation range of 501 to 1000 meters above sea level (masl) with an average elevation of 647 m (Municipal Planning and Development Office [MPDO], 2000). The dominant slope is 18% and above which covers almost 72% of the municipality’s area making it mountainous and with deep canyons and gorges. On the other hand, Malaybalay City, which is the capital of the province, is situated in the central part of the province with coordinates of $8^0$9’ north latitude and $125^0$5’ east longitude. On the average, the city is elevated (622 masl), and about 60% of its land area is above 30% slope. Consequently, it is characterized with steep hills, mountains and cliff-like streamside with the rest of the areas rolling and hilly.

In terms of climate, Impasugong is characterized to be cool and moist throughout the year due to its high elevation (MPDO, 2003). The area is under Type 3 climate which is characterized by the absence of pronounced maximum rainy period and a short dry season lasting from one to three months, usually starting from February up to April. Average temperature ranges from 16 to 31°C throughout the year. For the past five years, the heaviest rainfall occurred in June with 431.7 mm and the lowest in March with only 89.2 mm. It is a typhoon-free area, ideal for the production of high-value crops.

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 2664 mm, respectively. March is the driest with 115 mm rainfall while September is the wettest with an average of 328 mm rainfall. On the other hand, May is the warmest with an average temperature of 24.4 °C while January is the coolest with an average of 22.5 °C. 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.

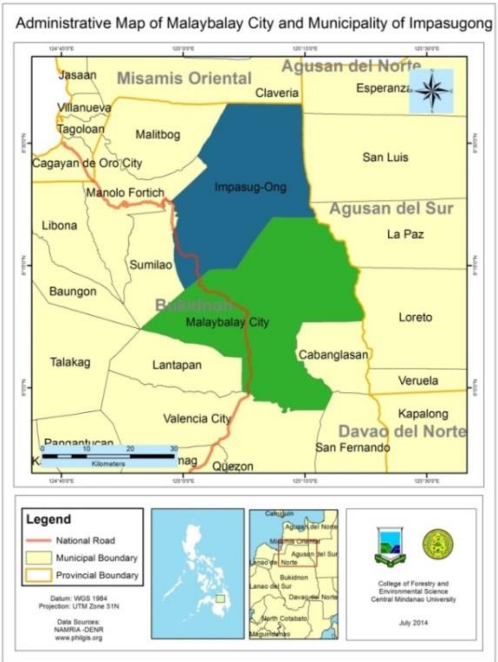

Figure 1. Location map of the study area.
Source: NAMRIA (http://www.namria.gov.ph/)

Plot establishment

The sampling protocol designed by Zemek (2009) was adopted with modification in this study. Three bamboo plantations were sampled, i.e. *D. asper*, *B. blumeana*, and *B. vulgaris*. Considering that the individual plantation area was comparably small and due to limited time and labor resources, only two sampling plots per bamboo plantation were purposively selected for a total of six plots. Each plot had a size of 5 x 20 m (100 m^2) and contained two to three groups of clumping bamboo (Figure 2).

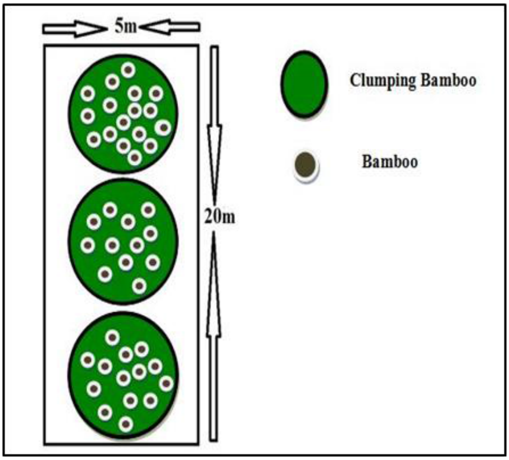

Figure 2. Diagram of a 5 x 20-m sampling plot.

Measurement of aboveground biomass

In each group of clumping bamboo within a 100-m^2 sampling plot, the following were determined: a) number of poles, b) total height of each pole using Haga altimeter, and c) diameter at breast height (1.3 m from the ground) of each pole using a diameter tape. Five individual poles in each clump were then randomly selected and sampled. After cutting each selected pole at breast height, total height was again determined with a measuring tape. Subsequently, aboveground components were separated into three: a) leaves, b) twigs and branches, and c) culms. Total fresh weight (FW) of each component was determined on site with a scale and sub-sample of 300 g each was taken to the Soil and Plant Analysis

Laboratory (SPAL) of Central Mindanao University in Musuan, Bukidnon for oven dry weight (DW) and carbon content determination. The equations below were used to convert sub-sample of dry biomass to total dry weight:

Total component DW (kg) = total FW * sub-sample DW / sub-sample FW

Biomass total (kg) = Average biomass per pole * number of poles

Calculation of aboveground carbon stock

Carbon stock in each bamboo component was calculated based on its corresponding dry biomass and carbon content. The carbon stock in biomass was calculated using the following formula:

$$CSi = TDWi * CFi$$

where *CSi* is carbon stock of component *i* in kg, *TDWi* is total dry weight of component *i* (biomass) in kg, and *CFi* is carbon content in biomass of component *i* in percent. Total carbon stock was then calculated as the sum of carbon stock of all sampled components.

Statistical analysis

Analysis of variance (ANOVA) and post-hoc analysis (Tukey's HSD) were used to determine significant differences in terms of biomass and amount of carbon sequestered among the three species considered in the study.

Results and Discussion

Biometric characteristic of bamboo species under study

On the average, the number of poles per clump in the three bamboo species under study ranges from 25 to 29 with *D. asper* having the highest (Table 1). This range is consistent with the study of Rojo (2007) which showed that *D. asper*, *B. blumeana* and *B. vulgaris* had more or less 30 culms per clump. *D. asper* also had the greatest diameter and total height with a mean of 16.6 cm and 24.2 m, respectively. Northern

Mindanao Consortium for Agriculture and Resources Research and Development [NOMCARRD] (2009) reported that *D. asper* is a large bamboo species which can reach a diameter of 22 cm and total height of 30 m. In contrast, *B. blumeana* had the smallest mean diameter at 7.3 cm only while *B. vulgaris* was the shortest with a mean height of 15.3 m. It is noted though that *B. blumeana* can attain a diameter of up to 15 cm (Clayton et al., 2006) while *B. vulgaris* can grow an average height of up to 15 m (Rojo, 2007).

Table 1. Biometrics of the three bamboo species under study.

Species	Number of Poles Per Clump	DBH, cm		Height, m	
		Range	Mean	Range	Mean
D. asper					
Plot 1					
Clumping bamboo 1	29	16.0-16.9	16.3	24.3-25.9	24.9
Clumping bamboo 2	27	15.9-16.8	17.1	23.5-27.8	23.0
Clumping bamboo 3	30	15.9-16.8	16.2	24.9-28.2	24.4
Plot 2					
Clumping bamboo 1	32	16.1-17.9	17.3	20.9-25.8	23.5
Clumping bamboo 2	29	15.8-17.1	16.1	22.5-27.6	25.4
Species Mean	29		16.6		24.2
B. blumeana					
Plot 1					
Clumping bamboo 1	23	4.0-8.5	6.8	15.0-24.3	19.2
Clumping bamboo 2	25	4.1-9.3	7.5	16.2-25.0	18.9
Plot 2					
Clumping bamboo 1	26	5.1-8.6	7.9	15.9-24.2	20.3
Clumping bamboo 2	25	4.5-10.0	8.1	15.9-24.9	19.9
Clumping bamboo 3	24	4.2-11.4	6.3	15.2-25.0	20.5
Species Mean	25		7.3		19.8
B. vulgaris					
Plot 1					
Clumping bamboo 1	28	5.0-8.9	8.4	10.2-19.8	15.4
Clumping bamboo 2	25	6.1-9.0	7.8	10.5-20.0	14.8
Plot 2					
Clumping bamboo 1	27	5.5-10.0	8.4	11.5-19.5	15.2
Clumping bamboo 2	25	5.8-9.8	7.4	10.0-20.1	15.9
Species Mean	26		8.0		15.3

Aboveground biomass density of bamboo species under study

As one of the fastest-growing plants, bamboos typically mature in less than 10 years bearing an increment biomass of 5 to 12 t ha^{-1} yr^{-1} (Lobovikov et al., 2009). Consequently, this plant could produce a high amount of biomass at a faster rate. As presented in Table 2, culms constitute the bulk of the aboveground biomass of the three bamboo species which ranges from 38.8% to 62.5% of the total. Düking et al. (2011) reported that culms possess the greatest capacity in terms of storing carbon in the live biomass of bamboos. *D. asper* yielded the highest aboveground biomass density with a mean of 177.63 t ha^{-1} which is statistically different when compared with the other two species. This value is comparable to that of other bamboo species such as a 12-year old *Gigantochloa levis* grown in the Philippines and a mature plantation of *Phyllostachys pubescens* in Japan which has an aboveground biomass of 146.8 t ha^{-1} and 137.9 t ha^{-1}, respectively (Suzuki & Jacalne, 1986; Isagi et al., 1997). This biomass value is even higher than that of the fast-growing *Gmelina arborea* (127 t ha^{-1}), which is used in forest plantations in the Philippines. The high biomass value of *D. asper* could be attributed to its relatively greater diameter and height, and the superior number of poles per hectare.

In contrast, *B. blumeana* and *B. vulgaris* produced significantly lower aboveground biomass density with a mean of 97.5 t ha^{-1} and 72.2 t ha^{-1}, respectively. The lower biomass values of these two species could be due to their lesser diameter and height values. For instance, mean diameter and height values of *B. blumeana* are only 7.3 cm and 19.8 m while that of *B. vulgaris* are only 8.0 cm and 15.3 m, respectively. As observed during the conduct of the study, *D. asper* was apparently well-managed while the two other bamboo species seemingly lacked proper care and maintenance as proliferating weeds such as grasses, and other vegetation are evident in the plantations (Figure 3). Virtucio and Roxas (2003) indicated that poor management practices in bamboo plantations may contribute to reduced production of culms and shoots. The biomass values of these species are expected though to increase as soon as they mature even in poorly managed stands. For instance, reported biomass of a mature plantation of *B. blumeana* in the Philippines is 143 t ha^{-1} (Isagi et al., 1997).

Table 2. Aboveground biomass density of each bamboo species under study.

Species	Aboveground Plant Component	Component Biomass in each pole, kg	No. of Poles Per Hectare	Aboveground Biomass Density, t ha^{-1}
D. asper				
	Leaves	3.4	8600	29.2
Plot 1	Twigs and branches	6.3	8600	54.4
	Culm	16.2	8600	139.7
Total		25.9		223.3
	Leaves	3.2	6100	19.5
Plot 2	Twigs and branches	6.6	6100	40.1
	Culm	11.9	6100	72.4
Total		21.7		132.0
Species Mean		23.8		177.6
B. blumeana				
	Leaves	2.6	4800	12.5
Plot 1	Twigs and branches	5.0	4800	24.2
	Culm	9.5	4800	45.6
Total		17.1		82.3
	Leaves	2.3	7500	17.6
Plot 2	Twigs and branches	5.2	7500	39.0
	Culm	7.5	7500	56.2
Total		15.0		112.8
Species Mean		16.1		97.5
B. vulgaris				
	Leaves	4.3	5300	22.7
Plot1	Twigs and branches	3.9	5300	20.6
	Culm	5.4	5300	28.6
Total		13.6		71.9
	Leaves	4.4	5200	22.9
Plot 2	Twigs and branches	4.1	5200	21.5
	Culm	5.4	5200	28.1
Total		13.9		72.5
Species Mean		13.8		72.2

Figure 3. From left to right are plantations of ***D. asper*****,** ***B. blumeana*****, and** ***B. vulgaris*** **in Bukidnon.** Note the apparent difference of the three plantations in terms of care and maintenance particularly weeding practices.

Aboveground carbon density of bamboo species under study

Considered as the tallest grass, bamboo is known to be one of the fastest-growing plants in the world which can develop at the rate of up to 1.2 m day^{-1} (Lobovikov et al., 2009). Since it can grow vigorously, it has great potential to sequester atmospheric carbon at a faster rate and be a valuable sink for carbon storage. Aboveground carbon storage is obtained by getting the product of organic carbon content in the biomass and the aboveground biomass density. Mean organic carbon content of the three species in this study ranges from 46.01 to 49.18% as shown in Tables 3 and 4. INBAR (2009) reported that about half (50%) of the total biomass of bamboos is carbon. Meanwhile, average aboveground carbon density of *D. asper* is 86.7 tC ha^{-1} which is statistically higher compared to those of *B. blumeana* and *B. vulgaris*. This is comparable to a fast-growing Philippine forest plantation species, *Acacia* sp., which yields a carbon density of 81 tC ha^{-1} (Lasco et al., 2000). It is, however, about 17% only of the carbon density of natural forest which is 518 tC ha^{-1}.

On the other hand, carbon density values of *B. blumeana* and *B. vulgaris* which are not statistically different from each other are roughly similar to that of another forest plantation species, *Tectona grandis*, which only has 35 tC ha^{-1}. The aboveground carbon density value of *B. vulgaris* (33.4 tC ha^{-1}) is also comparable to that of a coconut-based multi-storey system in Mt. Makiling, Philippines which yields 39 tC ha^{-1} (Zamora, 1999). Planting bamboos however is better off than allowing the land to become idle and vegetated with grasses. While grasslands also have the ability to sequester carbon, it is reported that *Imperata*- and *Saccharum*-dominated grasslands have only an aboveground carbon density values of 1.7 and 13.1 tC ha^{-1}, respectively (Lasco, 2007).

Table 3. Total carbon stored in the aboveground biomass of three bamboo species under study.

Species	Mean Organic Carbon Content, %	Aboveground Biomass Density, t ha^{-1}	Aboveground Carbon Density, tC ha^{-1}	Carbon Mean Annual Increment, t ha^{-1} yr^{-1}
D. asper (27 years old)				
Plot 1	48.41	223.3	108.1	4.0
Plot 2	49.18	132.0	64.9	2.4
Mean	48.8	177.6	86.7	3.2
B. blumeana (24 years old)				
Plot 1	46.76	82.3	38.5	1.6
Plot 2	47.62	112.8	53.7	2.2
Mean	47.19	97.5	46.1	1.9
B. vulgaris (24 years old)				
Plot 1	46.01	71.9	33.1	1.4
Plot 2	46.41	72.5	33.6	1.4
Mean	46.21	72.2	33.4	1.4

Table 4. One-way ANOVA of aboveground biomass and carbon stored in the three bamboo species.

Species	Mean Aboveground Biomass Density, t ha^{-1}	Mean Aboveground Carbon Density, tC ha^{-1}	Statistical Test (α=0.01)
D. asper	177.6^{a}	86.7^{a}	
B. blumeana	97.5^{b}	46.1^{b}	0.000
B. vulgaris	72.2^{b}	33.4^{b}	

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

In terms of rate of carbon sequestration, each year the 27 year-old *D. asper* can sequester an average of 3.2 tC ha^{-1} while the 24 year-old *B. blumeana* and *B. vulgaris* can absorb only about 1.9 and 1.4 tC ha^{-1}, respectively. These values are lower than that of a native bamboo in China called Moso bamboo (*Phyllostachys heterocycla*) which has an annual increment of 5.1 tC ha^{-1} (Li, 2013). The carbon sequestration rate of

D. asper is also a little bit lower than that of the 60 year-old *Pinus kesiya* plantation grown in Malaybalay City which has a rate of 3.99 tC ha^{-1} yr^{-1} (Patricio & Tulod, 2010). The low carbon sequestration rates of bamboo species in this study can be attributed to the constant harvesting of the stands leading to the reduction in their biomass. However, bamboos actually sequester more carbon during early years of plantation than fast-growing forest trees because of their fast growth rate (Kuehl & Castillo, 2012). In fact, Sakurai et al. (1994) reported that reforestation species in Nueva Ecija, Philippines such *as Acacia auriculiformis, Tectona grandis, Gmelina arborea* and *P. kesiya* with ages ranging from 6-13 years old had carbon sequestration rates between 0.55 to 3.73 tC ha^{-1} yr^{-1} only.

Conclusion and Recommendations

The results of the study indicate that the three bamboo species grown in plantations in Bukidnon, Philippines have the potential to store atmospheric carbon. Aboveground carbon density of these species goes in the following order: *D. asper* (86.7 tons C ha^{-1}) > *B. blumeana* (46.1 tons C ha^{-1}) > *B. vulgaris* (33.4 tons C ha^{-1}). These represent 6.4-16.7% of the carbon stored in natural forests in the Philippines.

It is highly recommended that plantation managers and caretakers should incorporate appropriate silvicultural management practices that would enhance higher biomass production and greater carbon sequestration potential of these bamboo-stands. Policies and programs that advocate the establishment of bamboo plantations particularly using *D. asper* species in degraded, marginal and idle lands in the country should also be supported. While bamboos provide local communities with wide socioeconomic benefits, their ecological importance particularly in climate change mitigation should be recognized, highlighted and advocated in the policymaking, and research and development arena.

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