Full Paper

Journal of Agricultural Research, Development, Extension, and Technology, 3(1), 60-70 (2021)

Aboveground biomass and carbon stock of Buho (*Schizostachyum lumampao* (Blanco) Merrill) in Cuyambay, Tanay, Rizal

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Received: March 2, 2021
Revised: July 24, 2021
Accepted: September 6, 2021

Abstract

This study aimed to quantify the aboveground biomass and carbon stock of Buho (*Schizostachyum lumampao*) in Cuyambay, Tanay, Rizal, Philippines, and develop allometric equations for predicting aboveground biomass. Ten plots (5 m x 5 m) in an elevation ranging from 419-460 meters above sea level (masl) that contained one group of clumping bamboos were randomly established. Three culms were harvested from each clump for a total of thirty culms. The Buho in Sitio Tablon had a mean height (H) of 8.37 m, diameter at breast height (DBH) of 6.46 cm and thickness at breast height (TBH) of 6.05 mm. The mean aboveground biomass and carbon stock densities were 74.19 ton·ha^{-1} and 31.35 ton·ha^{-1}, respectively. The culm had the highest contribution to aboveground biomass and carbon stock density, followed by the branches, then the leaves. These results demonstrate the potential of Buho to store atmospheric carbon at a level comparable to that of other tree plantation species. Allometric regression revealed that 70.0% of the variance in culm biomass can be explained by DBH^{2}H.

Keywords - Aboveground biomass, Buho, carbon stock, *Schizostachyum lumampao*

Introduction

Greenhouse gases (GHG), especially carbon dioxide (CO_2), have increased markedly since 1750, and have now exceeded the natural range over thousands of years (Cubasch et al., 2013). In mitigating climate change effects through carbon dioxide sequestration, several species of bamboo were shown to have a high potential as a carbon sink (Patricio & Dumago, 2015; Sohel et al., 2015; Yiping et al., 2010). Further, with its fast growth rate, bamboo is relatively efficient in sequestering carbon from the atmosphere (Lantican, 2016).

In addition to its potential environmental benefits, bamboo is also economically and industrially important as it is used for house construction, farm implements, furniture and handicraft (Pabuayon, 2004; Salzer et al., 2016). As such, bamboo products provide livelihood and income, and contribute to the Philippines' local and export economy (Pabuayon, 2004).

Because bamboo is fast-growing, able to grow 90-120 cm in one day (Lobovikov et al., 2009), it is often seen as ideal for carbon sequestration (Lantican, 2016; Scurlock, et al., 2000). However, fast growth alone cannot be seen as a guarantee for net carbon sequestration (Düking et al., 2011). Bamboo, like other plants, convert carbon from the atmosphere, but most of this carbon is released back. Although only a certain portion is sequestered in the plant biomass, plants with larger biomass have higher potential for carbon sequestration (Lasco, 2007). If harvested culms are not left to decompose, and are instead used to make durable bamboo products, then net carbon sequestration occurs (Düking et al., 2011).

There are around 60 known bamboo species in the Philippines (Roxas et al., 200), among which 12 are economically important, including Buho (*Schizostachyum lumampao*) (Landicho, 2016). It is a native bamboo species in the Philippines, and grows extensively in natural stands in Northern Luzon, Panay, and Basilan (Roxas, 2012), and has also adapted in the Southern Tagalog region (Tongco

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et al., 2013). Buho grows in clumps; its culms are erect and typically 10-15 m tall, 4-8 cm in diameter, with walls 4-10 mm thick (Roxas, 2012). The culms are widely used for bamboo matting known as *sawali*, and also for making baskets, fences, spears, fish pens, flutes, handicrafts and for many other purposes (Food and Agriculture Organization of the United Nations, 2006), including construction, plybamboo panels, and paperpulp (Roxas, 2012).

Previous studies have investigated the morphometric measurements, aboveground biomass and carbon content of Buho (Lantican, 2016; Pongon, 2016; Suzuki & Jacalne, 1986). These studies were conducted in various locations, namely at the foot of Mt. Makiling, at around 100 meters above sea level (masl) (Suzuki & Jacalne, 1986), at Barangay Camp 1 in Maramag, Bukidnon, at around 300 masl (Pongon, 2016), and in six unnamed sites (two each in Luzon, Visayas, and Mindanao) with a mean elevation of 347 masl (Lantican et al., 2017). Results of these studies indicate that morphometric characteristics and aboveground biomass density of Buho may vary (see Table 1).

Since biomass accumulation may vary across bamboo species (Lantican, 2016) and even among bamboo of the same species (Table 1), this study aimed to quantify the aboveground biomass and carbon stock of Buho (*S. lumampao*) in Cuyambay, Tanay, Rizal, Philippines. Specifically, the study aimed to measure the height (H), diameter at breast height (DBH), and thickness at breast height (TBH), and to calculate the total aboveground biomass (culm, leaves and twigs/branches) and carbon content of Buho in Cuyambay. In addition, these measurements were used to develop allometric models for estimating the biomass of Buho, which could be useful for regional and large-scale comparisons. The results of study can add to the literature on Buho, and serve as the basis for more effective interventions in managing and developing bamboo plantations.

Research Methods

The Study Site

The study site was situated at approximately 14.5877°N latitude, 121.3101°E longitude, in Sitio Tablon, Barangay Cuyambay, in Tanay, Rizal, in the island of Luzon (Figure 1). Mean elevation at these coordinates is estimated at 577 meters above sea level (https://elevation.maplogs.com) which is within the elevation range of 135-700 masl for Buho growth (Lantican, 2016). The area has Type II Climate with sandy-loam soil. Within the sampling site, the bamboos were naturally grown and were located in patches.

Sampling

Ten plots were randomly chosen by placing 10 random points in the map of Cuyambay where

Table 1. Reported biometric characteristics and aboveground biomass density of Buho

Reference	Elevation (masl)	Pole density	Diameter at breast height (DBH, cm)	Height (m)	Thickness at breast height (TBH, mm)	Aboveground biomass density (ton·ha^{-1})
Suzuki & Jacalne (1986)						
Mean	≈100	38017	3.5	8.6	–	58.2
Pongon (2016)						
Mean	≈300	5275	5.2	10.93	5.9	34.49
Range			4–8	8.5–12.45	40–80	–
Lantican et al. (2017)						
Mean	347		5.1	10.9	–	–
Range	135-700		1.6-8.2	5.6-16.9	–	–

bamboos were seen growing (Figure 2). The closest clump of bamboo to each of the ten random points was chosen as the plot. Global positioning system (GPS) was used to collect data on coordinates these plots and define boundaries. Each plot had a size of 5m × 5m (25 m^2) containing one group of clumping bamboos (Figure 3). The coordinates and elevation profile are shown in Table 2.

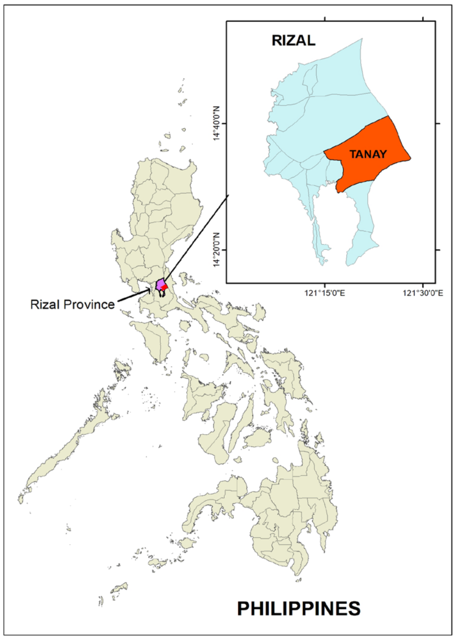

Figure 1. Location of the study

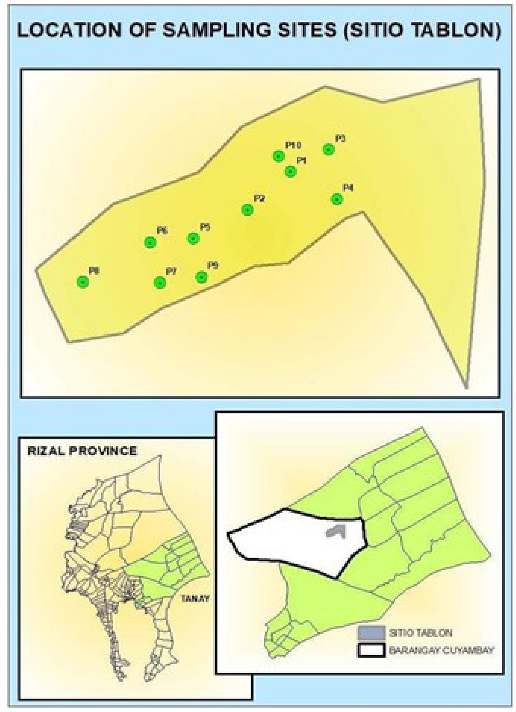

Figure 2. Location of sampling plots

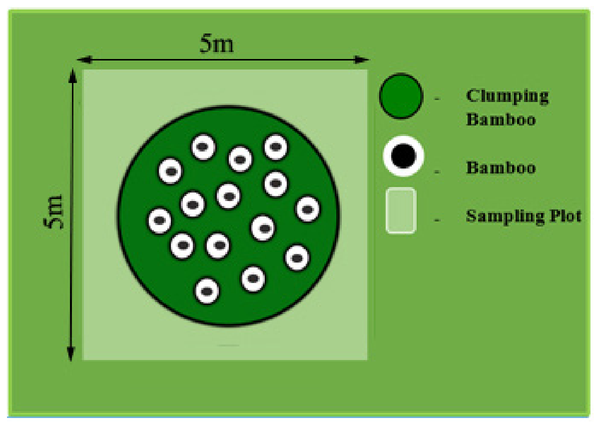

Figure 3. Diagram of a 5m x 5m sampling plot

In each sampling plot, culms were marked in numbers. Three sample culms were selected using simple random sampling (SRS) technique by drawing lots. Selected bamboo plants were free from any signs of damage by herbivores, humans or from any other physical factors.

The samples were harvested using a rip cut saw at the end of February when the rainy season had ended. Buho were harvested in the morning before the sun is completely on its peak.

Biometric Characteristics and Aboveground Biomass

The following data were collected: total number of poles per clump, the diameter and thickness at breast height (1.3 m from the ground), and the total height of each culm harvested. The diameter at breast height (DBH) and thickness at breast height (TBH) were measured using a digital caliper. The total height was measured using meter tape after felling the bamboos.

To determine biomass allocation, the plants were sorted into three components—culm (aerial stem), branch, and leaf. Total fresh weight of each component was measured immediately with a suspension balance. Subsamples were taken from the middle portion and the two opposite end parts of the culm to get the representative ratio of the whole culm. The culm subsamples were freely cut out using a rip cut saw. The subsample weights were measured using a digital balance. A minimum of 300 g of subsamples of each component of bamboo were taken to the laboratory to obtain the oven dry weight as suggested (Huy & Long, 2019; Patricio & Dumago, 2014; Pongon et al., 2016;). Dry weight

Table 2. Location of the ten established sampling plots

Sampling plot	GPS coordinates	Elevation (masl)
1	121.3394°N, 14.5986°E	419
2	121.3380°N, 14.5972°E	429
3	121.3407°N, 14.5994°E	427
4	121.3410°N, 14.5976°E	430
5	121.3362°N, 14.5962°E	421
6	121.3347°N, 14.5961°E	446
7	121.3351°N, 14.5947°E	460
8	121.3324°N, 14.5946°E	536
9	121.3364°N, 14.5948°E	426
10	121.3385°N, 14.5983°E	427

was obtained by oven drying the subsamples at 80ºC for 72 hours, following the procedures specified by Pongon et al. (2016) and Xayalath et al. (2019). Mean dry weight for the three culm subsamples were later calculated.

Calculation of Aboveground Biomass (AGB)

The ratio of dry weight/fresh weight was used to obtain the total dry matter (biomass) for each component of the culm. Equations 1 and 2 were adapted from Patricio and Dumago (2014).

Equation 1:

$$TDW = TFW \times \frac{SDW}{SFW},$$

where
TDW = Total dry weight (biomass)
TFW = Total fresh weight
SDW = Sub-sample dry weight
SFW = Sub-sample fresh weight

Equation 2:

$$TB_{ABG} = TDW \times P,$$

where
TB_{ABG} = Total aboveground biomass density (ton·ha^{-1})
TDW = Total dry weight (biomass) per pole (ton)
P = Pole density (number of poles per hectare)

Calculation of Aboveground Carbon Stock

The carbon stock in each bamboo component was approximated based on the reported carbon content of the different parts of Buho (culm, branch/twigs and leaves) recorded in various parts of the Philippines in the Ecosystem Research and Development Bureau (ERDB) study (Lantican, 2016). In the ERDB study, the carbon content in the pole, leaves, and branches of Buho were 44.6%, 35.3%, and 39.5%, respectively. From these values, the carbon stock density was calculated based on the following formula (Patricio & Dumago, 2014).

Equation 3:

$$CS = TB_{ABG} \times CC,$$

where
CS = Carbon stock
TB_{ABG} = Total aboveground biomass density
CC = Carbon content (%)

Table 4. L Total aboveground biomass density and carbon stock density of Buho components (ton·ha^{-1}), averaged across the three sampled culms

Sampling plot	No. of culms per clump	Pole density (ha^{-1})	Component	Aboveground biomass (dry weight, kg)	Above-ground biomass density, (ton·ha^{-1})	Carbon content (%)	Aboveground carbon stock density, (ton·ha^{-1})
1	37	14800	Culm	2.95	43.63	44.6	19.46
			Branches	0.95	14.09	39.5	5.57
			Leaves	0.92	13.57	35.3	4.79
			Total	4.82	71.29		29.81
2	34	13600	Culm	3.60	48.99	44.6	21.85
			Branches	0.93	12.68	39.5	5.01
			Leaves	1.11	15.15	35.3	5.35
			Total	5.64	76.82		32.21
3	37	14800	Culm	3.88	57.44	44.6	25.62
			Branches	0.93	13.73	39.5	5.42
			Leaves	0.77	11.32	35.3	4.00
			Total	5.57	82.50		35.04
4	38	15200	Culm	2.87	43.58	44.6	19.44
			Branches	1.23	18.70	39.5	7.39
			Leaves	0.58	8.77	35.3	3.10
			Total	4.67	71.04		29.92
5	28	11200	Culm	4.09	45.77	44.6	20.41
			Branches	1.01	11.33	39.5	4.48
			Leaves	0.78	8.75	35.3	3.09
			Total	5.88	65.86		27.98
6	28	11200	Culm	3.90	43.67	44.6	19.48
			Branches	0.73	8.21	39.5	3.24
			Leaves	0.70	7.84	35.3	2.77
			Total	5.33	59.72		25.49
7	36	14400	Culm	3.12	44.91	44.6	20.03
			Branches	1.13	16.24	39.5	6.41
			Leaves	0.38	5.40	35.3	1.91
			Total	4.62	66.56		28.35

Table 4. (Continued)

Sampling plot	No. of culms per clump	Pole density (ha^{-1})	Component	Aboveground biomass (dry weight, kg)	Above-ground biomass density, (ton·ha^{-1})	Carbon content (%)	Aboveground carbon stock density, (ton·ha^{-1})
			Culm	3.60	61.89	44.6	27.60
8	43	17200	Branches	1.27	21.90	39.5	8.65
			Leaves	0.82	14.14	35.3	4.99
			Total	5.69	97.92		41.24
			Culm	3.25	48.06	44.6	21.43
9	37	14800	Branches	0.54	7.96	39.5	3.14
			Leaves	0.73	10.82	35.3	3.82
			Total	4.52	66.84		28.40
			Culm	4.29	54.96	44.6	24.51
10	32	12800	Branches	0.99	12.66	39.5	5.00
			Leaves	1.23	15.72	35.3	5.55
			Total	6.51	83.34		35.06
MEAN					74.19		31.35

Total Aboveground Biomass Density of Buho

Table 4 shows the pole density, aboveground biomass and aboveground carbon density of Buho sampled in this study. The highest aboveground biomass density was 97.92 ton·ha^{-1} (Plot 8) and lowest was 59.72 ton·ha^{-1} (Plot 6).

The mean aboveground biomass density was 74.19 ton·ha^{-1}, which is higher than in earlier reports (see Table 1). This higher result in this study may possibly be due to the larger DBH and TBH as shown in Table 3. Another possible reason might be the higher pole density in this study (11,200-17,200 poles per hectare), as compared to the 5,275 poles per hectare in Pongon et al.'s (2016) study (see Table 1).

The aboveground biomass density of Buho in Sitio Tablon was less than that of other bamboo species such as *Dendrocalamus asper* (Schult. & Schult. f.) Backer ex Heyne (Giant Bamboo) with an aboveground biomass density of 177.6 ton·ha^{-1} and *Bambusa blumeana* (Schult. & Schult. f.) (Kawayan Tinik) with an aboveground biomass density of 112.8 ton·ha^{-1} (Patricio & Dumago, 2014).

Total Aboveground Carbon Stock Density of Buho

Across all ten plots, the mean total aboveground carbon stock density was 31.35 ton·ha^{-1}, and ranged from 25.49 ton·ha^{-1} (Plot 6) to 41.24 ton·ha^{-1} (Plot 8). Furthermore, the mean aboveground carbon stock density of Buho in Sitio Tablon was comparably higher than the 17.96 ton·ha^{-1} reported by Pongon et al. (2016), possibly because of the higher culm density, and larger DBH and TBH in this study. For comparison, the reported aboveground carbon stock density of other bamboo species were 14.58 ton·ha^{-1} for the drought-resistant bamboo species *Oxytenanthera abyssinica* in Northern Ethiopia (Darcha & Birhane, 2015), 25.56 ton·ha^{-1} for *Bambusa philippinensis* (Laak) (Pongon et al., 2016), 33.4 ton·ha^{-1} for Kauayang Kiling (*Bambusa vulgaris*) (Patricio et al., 2014), and 86.7 ton·ha^{-1} for *D. asper* (Patricio et al., 2014).

Carbon sequestered by Buho in Sitio Tablon is greater than by deforested land, even when covered by grassland or crops. For example, the grasses *Imperata* and *Saccharum* only have an aboveground carbon density values of 1.7 and 13.1 ton·ha^{-1}, respectively (Lasco, 2007).

The total carbon stocks were calculated as the sum of carbon stock of all sampled components.

Data Analysis

The data that were gathered in this study were tabulated. The maximum and minimum values as well as the mean across all ten plots were calculated. This study utilized standard allometric equations for predicting biomass based on DBH and H (Li et al., 2016; Xayalath et al., 2019). The equation is the function $y = ax^b$, where y is the component (culm, branch, leaves) or total aboveground biomass, and x is DBH or alternatively, DBH^2H. Subjecting the data to allometric regression will determine which variable or variables (i.e., DBH or DBH^2H) lead to significant correlations with component or total aboveground biomass.

Result and Discussion

Morphometric Data of Buho

Table 3 shows the morphometric data of Buho. The mean height of the sampled culms ranged from 6.60 m (Plot 7) to 9.87 m (Plot 10), and the average mean height was 8.37 m. The mean DBH was 6.46 cm, ranging from 5.96 cm (Plot 1) to 6.82 cm (Plot 10), The mean TBH across the ten plots was 6.05 mm, which ranged from 5.40 mm (Plot 1) to 7.17 mm (Plot 7). Buho in Sito Tablon have lower mean height, larger mean diameter, and and thicker walls compared to the corresponding measurements in other studies (see Table 1). Possible reasons for the varying results can be different environmental conditions and/or differences in resource (water, light, nutrients, etc.) requirement and utilization efficiency which may affect the growth status of the bamboo (Nath et al., 2009).

Table 3. Location of the ten established sampling plots

Sampling plot	Height of sampled culm (m)		Diameter of sampled culm (cm)		Thickness of sampled culm (mm)	
	Range	Mean	Range	Mean	Range	Mean
1	6.87-8.90	7.99	5.72-6.20	5.96	4.38-6.47	5.40
2	8.64-9.00	8.83	5.90-6.45	6.23	5.40-6.83	6.04
3	7.92-10.5	9.44	6.20-6.83	6.49	6.10-6.84	6.43
4	6.90-8.30	7.62	5.73-6.37	6.51	5.75-6.46	6.00
5	7.35-9.70	8.52	5.90-7.72	6.77	4.73-6.28	5.59
6	5.80-11.5	8.83	6.02-7.42	6.75	5.38-6.82	5.89
7	4.10-9.20	6.60	6.03-7.05	6.53	6.90-7.55	7.17
8	5.80-8.30	6.99	6.15-6.57	6.46	5.22-6.46	5.97
9	8.10-9.80	8.97	5.54-6.37	6.03	5.21-6.33	5.66
10	7.60-12.5	9.87	6.18-7.58	6.82	5.50-7.36	6.31
Mean		8.37		6.46		6.05

The results indicate that Buho can store carbon, in common with other tree species even though trees have very different sequestration patterns. Hence, Buho shows potential in carbon dioxide sequestration for sustaining current biomass and carbon store estimates for Philippine forests and for assisting national carbon accounting processes.

Comparison Between the Components of Buho

Table 5 shows the mean aboveground biomass density of each component of Buho. The highest mean aboveground biomass density was in the culm (49.29 ton·ha^{-1}), followed by the branch component (13.75 ton·ha^{-1}) and the leaves (11.15 ton·ha^{-1}). These results are consistent with those of Gurmesa et al. (2016) who observed that the ratio of dry/fresh mass is highest for culm and the lowest is for leaves. Düking et al. (2011) reported that the culm has the greatest capacity to store carbon in the live biomass of bamboos.

With regards to aboveground carbon stock density, the highest contributor was the culm (21.98 ton·ha^{-1}), followed by the branch (5.43 ton·ha^{-1}) and then the leaves (3.94 ton·ha^{-1}). This finding showed a similar trend with the study of Nath et al. (2009) which reported that the allocation of carbon was more in culm components (53.05 ton·ha^{-1}) than in branch (5.81 ton·ha^{-1}) and leaf (2.19 ton·ha^{-1}). The findings clearly show that the culm part of bamboo contributes most to the carbon density, as compared to the branch and leaves.

Allometric Relationships

The data in this study formed the basis for allometric equations that relate various physical parameters of Buho. The results of the analysis are shown in Table 6.

Three significant correlations were found. These were between DBH^{2}H and the culm dry weight (R^2 = .700, p = 0.003), between DBH^{2}H and height (R^2 = .695, p = 0.03), and between DBH and culm dry weight (R^2 = .431, p = 0.039). The scatterplots for these three relations are shown in Figure 4. Other studies have also showed that DBH or DBH^{2}H have a strong linear relationship with the culm or total aboveground biomass. This was observed in thorny bamboo in Taiwan (Li et al., 2016) and in 11 bamboo species in Laos (Xayalath et al., 2019). Further, in common with this study, other studies have shown that there is no clear trend showing branch or leaf biomass as a function of DBH or DBH^{2}H (Li et al., 2016; Xayalath et al., 2019).

In this study, height was found to contribute substantially to the predictability of the model. Figures 4a and 4b show that based on the proportion of variance explained by the model (R^2), DBH^{2}H was a better predictor (R^2 = 0.700) than DBH (R^2 = 0.431) for culm biomass. Thus, it seems that the determination of bamboo height is warranted, even if this measurement is not as easily obtained as culm diameter. Note that there are non-destructive methods to determine height, such as the use of trigonometry (Hairiah et al., 2001) or more modern methods such as terrestrial laser scanning (Calders et al., 2015). A further improvement in the estimating biomass can be achieved by including wood specific gravity as an estimator (Chaturvedi et al., 2010; Chave et al., 2005; van Breugel et al., 2011), or by testing other allometric equations (Mavouroulou et al., 2014).

Table 5 Mean aboveground biomass density and mean aboveground carbon stock density across all sampled plots

Bamboo component	Mean aboveground biomass density (ton·ha^{-1})	Component percentage (%)	Mean aboveground carbon stock density (ton·ha^{-1})	Component Percentage (%)
Culm	49.29	66.44	21.98	70.12
Branch	13.75	18.53	5.43	17.32
Leaves	11.15	15.03	3.94	12.56

Table 6. Allometric equations for biomass (culm, branches, leaves) and total aboveground biomass (kg) of Buho as a function of DBH or DBH^2H

	a	*b*	R^2	*p*
DBH-Culm	0.0913	1.9602	0.431	0.039*
DBH-Branch	0.0292	1.8656	0.120	0.328
DBH-Leaf	2.3704	-0.606	0.007	0.813
DBH-AGB	0.3026	1.5351	0.349	0.072
DBH-H	4.5907	0.318	0.013	0.752
DBH^2H-Culm	0.0609	0.6944	0.700	0.003*
DBH^2H-Branch	7.9649	-0.365	0.059	0.498
DBH^2H-Leaves	0.0033	0.932	0.227	0.164
DBH^2H-AGB	0.02657	0.5118	0.502	0.022
DBH^2H-Height	0.1951	0.6418	0.695	0.003*

DBH = diameter at breast height; AGB = aboveground biomass; H = height
*Significant at 0.05 level of significance

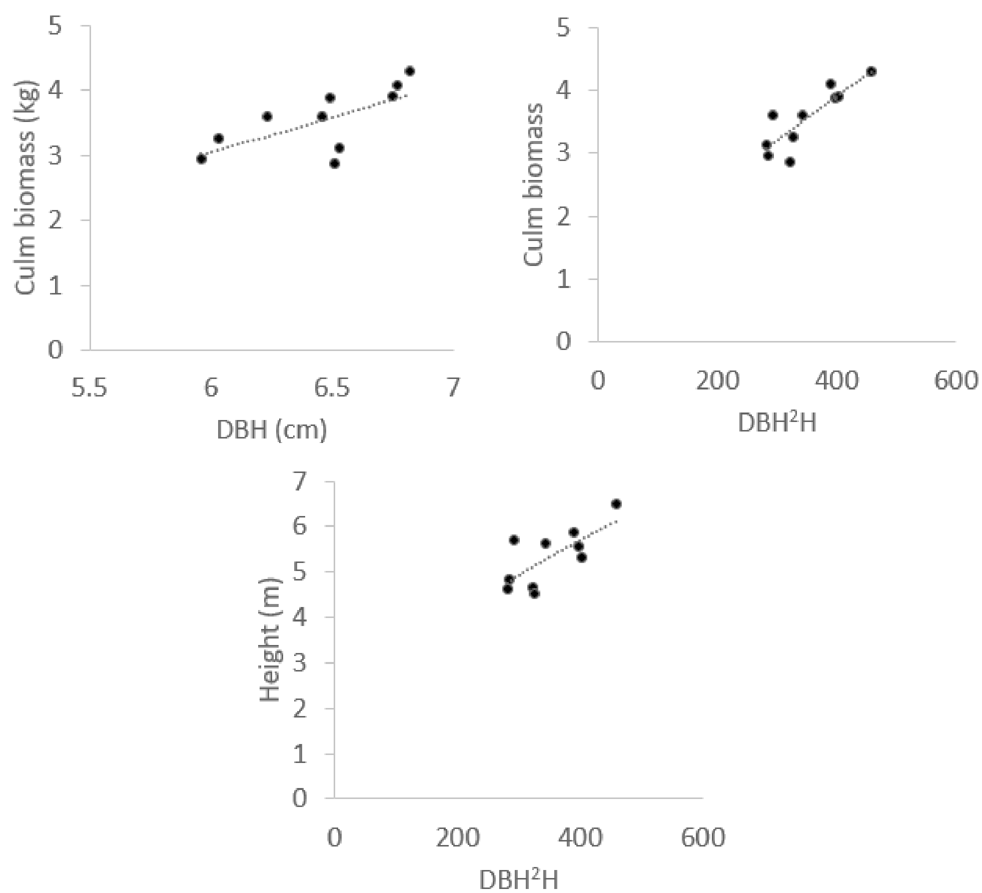

Figure 4. Scatter plots of (a) culm biomass and DBH, (b) culm biomass and DBH^2H, and (c) height and DBH^2H

Summary and Conclusion

The study measured the height, DBH, and TBH of Buho in Sitio Tablon, which were found to differ with other reports. The study also calculated the mean aboveground biomass density of Buho in Sitio Tablon to be 74.19 ton·ha^{-1}. Furthermore, this study determined the mean aboveground carbon stock density of Buho in Sitio Tablon to be 31.35 ton·ha^{-1}, most of which is contributed by the culm component (70.12%). Results demonstrate the potential of Buho to store atmospheric carbon at a level comparable to that of other tree plantation species.

Allometric equations showed that DBH^{2}H was better than DBH for predicting culm biomass. However, the proportion of variance explained by the DBH^{2}H (R^2 = 0.700) was not very large. Further improvements to the model, possibly through the use of other allometric equations or other variables (such as wood specific gravity) are warranted.

Buho is known for its wide range of uses. Results of this study indicate that converting grassland to bamboo plantations and promoting bamboo products can help in mitigating climate change. This study can serve as a baseline study for future studies in line with the contribution of the potential capability of bamboo to store and sequester atmospheric carbon.

Disclosure Statement

No potential conflict of interest was declared by the authors.

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