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Determination of Aboveground Carbon Density of Mangium (*Acacia mangium* Willd.) using Biomass Expansion Factor

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Abstract

*Quantifying the impact of smallholder tree plantation to better design prescriptions tailored to promote climate change mitigation is essential. The study was undertaken to assess the aboveground carbon dioxide sequestration potential of Acacia mangium. Fifty temporary circular sample plots were established comprising 3,910 trees. The aboveground carbon density of A. mangium Willd. was determined non-destructively using Brown and Lugo formula, "AGB (ton per tree) = volume over bark (m^3 per tree) * wood density (g cm^{-3}) * biomass expansion factor (BEF). The study was able to develop a new biomass expansion factor equation for A. mangium Willd. The results of the study showed that as tree age increases, the tree biomass and carbon density also increases, but at slower rate from 3-17 yrs. The average aboveground biomass density of A. mangium at ages 3, 10 and 17 years were 3.33, 33.06 and 73.09 t ha^{-1}, respectively. On the other hand, the mean aboveground biomass density increment at site indices 12, 15, 18, 21 and 24 were 4.04, 4.40, 4.99, 5.47 and 5.86 t ha^{-1}, respectively. This study explicitly showed the great potential of smallholder A. mangium plantation in sequestering carbon dioxide.*

***Keywords**:* carbon, mangium, modelling, BEF, yield

1. Introduction

Acacia mangium Willd or *A. mangium*) is a tropical tree species capable of colonizing difficult sites. It is important attributes include rapid early growth, good wood quality (for pulp, sawn timber, and fuel wood), and tolerance of a range of soil types and pH (Hediyanti and Sulistyawati, 2010). This uniqueness made *A. mangium* as one of the main component in national forestation programs.

Besides its potential for wood production for local and national wood-based industries, smallholder *A. mangium* plantation also provides environmental services such as carbon sequestration given the high growth rate of the species. Given the opportunity to sell the carbon sequestered during afforestation/ reforestation (A/R) for climate change mitigation, information on the capacity of smallholder *A. mangium* plantation in sequestering carbon dioxide under various environmental conditions is needed. The information on carbon sequestration can also be used by government agencies and local government units in developing policies and guidelines pertaining to environmental services in their respective local, provincial and regional jurisdictions.

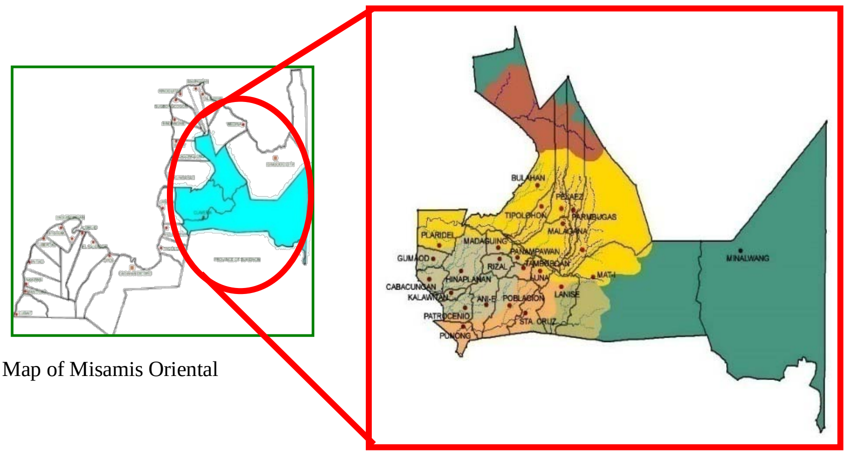
Stand volume (m^3 ha^{-1}) can be converted into carbon stock (t ha^{-1}). Assessment of forest structure and condition necessitate tree biomass estimation (Chave *et al.,* 2005; Chaidez, 2009), forest productivity, carbon stock and fluxes based on sequential changes in biomass, sequestration of carbon dioxide in biomass components and can also be used as an indicator of site productivity (Chaidez, 2009).

Despite the abundance of biomass equations for tropical tree species (Brown *et al.,* 1989; Overman *et al*., 1994; Chambers *et al*., 2001; Chave *et al*., 2005, Chaidez, 2009), there is an increasing interest in the accurate measurement of forest carbon stock (VandeWalle *et al*., 2005; Brown, 2002). Many carbon stock assessment studies have adopted equations without changing the site-specific coefficients and validation with a separate and locally-derived data. Several authors pointed the need to develop local and species-specific equations that provide more accurate estimation of the biomass because trees of different species differ significantly in terms of wood density, amount of foliage and other structures (Pearson *et al*., 2007; Iglesias, 2007, Black *et al*., 2004).

Woody biomass is an important indicator that provides a comprehensive measure of the capacity of forest ecosystem to sequester carbon dioxide. Hence, forest biomass provides estimation of the carbon pools in forest vegetation. An essential aspect of the study of carbon stock and the global carbon balance is estimating biomass (Brown, 1997). Estimates of biomass density provide the means for calculating the amount of carbon dioxide (CO_2) that can be sequestered in the atmosphere by regenerating the forest or by plantations, since the rate of biomass production is established. There are two approaches in estimating biomass density: 1) use of existing measures volume estimates (Volume over a Bark per hectare) converted to biomass density (t ha^{-1}) using a variety of tools; and, 2) estimate biomass density using biomass regression equations. Hence, the study was undertaken to: 1) develop local and site-specific biomass expansion factor (BEF); and, 2) determine the aboveground carbon stock in the living biomass of smallholder *A. mangium* plantations.

2. Methodology

The research study was conducted in the Municipality of Claveria, Misamis Oriental, Philippines covering nine barangays (Figure 1). The elevation ranges from 320 to 1,260 meters above sea level (masl). Most soils have a deep soil profile (>1 m) and rapid drainage. The soil is classified as fine, mixed, isohyperthermic UlticHaplorthox, with types ranging from clay to silty clay loam derived from volcanic parent material. Soils are generally acidic (pH 3.90 to 5.20), with low cation exchange capacity (CEC), and low to moderate organic matter content (1.80 %). Soils have high aluminum saturation, and low levels of available phosphorus and exchangeable K (Garrity and Agustin, 1995).



Map of Misamis Oriental

Figure 1. Location map of the study sites

Data on diameter, height, spacing and number of trees were taken from fifty temporary sample plots from different smallholder *A. mangium* plantations. Using a 10% sampling intensity, a circular plot having 18 m in radius was established (Figure 2). The sample size of 50 plots had reached the desired level of 15 to 20 observations for each independent variable (Hair *et al.*, 1998).

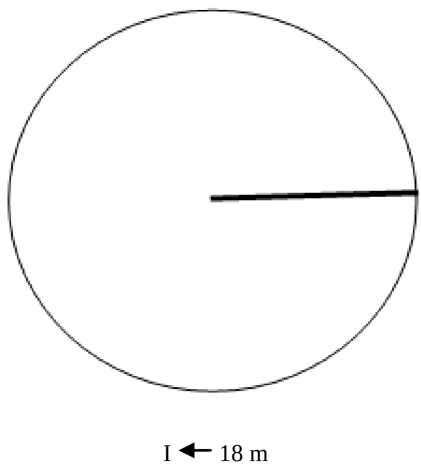


Figure 2. Lay-out of the temporary sample plot

A total of 3,910 “in” trees in each plot were measured for merchantable portion, total height (TH) and diameter at breast height (DBH). The measurement of the merchantable portion was based on the first large branch of the trees using a clinometer (PM-5, SUUNTO). The DBH of all trees in the plot was measured at 1.30 m from the base.

Age of trees was reckoned from the year the trees were planted. The “guessed-age” was determined through interviews with the owners or caretakers. Spacing of trees was determined by direct measurement of distance between trees as they are established in the field.

Wood density was defined as the oven-dry mass per unit of green volume (either in g or cm^3). Wood density was necessary to calculate above ground biomass density (Brown and Lugo, 1992). The biomass density of *A. mangium* plantation was calculated from biomass inventoried volume per hectare and then expanding this value to take into account the biomass of other aboveground components (Brown and Lugo, 1992).

Volume equation developed by the Ecosystem Research and Development Bureau of the Philippine Department of Environment and Natural Resources for *A. mangium Willd*. was used (Lanting *et al.*, 2008). The equation was validated using a separate set of data taken within the research sites before it was adopted.

$$\text{Log (VOL)} = -3.91249 + 1.97698\text{Log (DBH)} + 0.66279\text{Log (MH)} \quad (1)$$

Biomass expansion factor (BEF) was derived using biomass inventoried volume (BV) as the independent variable. The BV values were generated as a product of volume over bark (VOB) expressed in $m^3\ ha^{-1}$ and wood density (WD). The preliminary values of the BEF values were determined using the Brown and Lugo (1992) equation:

$$\text{BEF} = \text{Exp}\ \{3.213 - 0.506 \times \text{Ln (BV)}\} \quad (2)$$

The BV and BEF data were diagnosed using regression diagnostics for the presence of outliers, influential data, collinearity and others. Multiple linear regression was used to derive the coefficients of different independent variable. The BEF model was selected based on the following criteria used in developing the yield model:

1. Goodness of fit as indicated by the coefficient of determination ($R^{2)}$
2. Significant p > |t| value
3. Small root mean square error (RMSE)

Density of *A. mangium* wood was generated from the common regression equation developed by Reyes *et al*. (1992) to convert WD based on 12% moisture content (MC) to WD based on oven-dry mass and green volume, as shown below:

$$Y = 0.0134 + 0.800X \quad (3)$$

where

Y = wood density based on oven dry mass/ green volume
X = wood density based on 12% MC

The general equation developed by Brown and Lugo (1992) for aboveground biomass density was used in estimating BV as follows:

$$\text{Aboveground biomass density (t ha}^{-1}\text{)} = VOB * WD * BEF \qquad (4)$$

where

WD = volume weighted average wood density (1 of oven-dry biomass per m^3 green volume)

BEF = biomass expansion factor

VOB = inventoried volume over bark free bole (m^3 ha^{-1})

3. Results and Discussion

3.1 Biomass Expansion Factor

Using STATA v. 10 statistical software, the coefficients, RMSE, R^2 and P > |t| value were determined. The BV and constant are highly significant at 0.01 level based on the individual P value of the regression coefficients. The regression coefficients in the model are shown in Table 1. The equation from two parameters of the exponential growth curve was:

$$BEF = B1 \times B2^{BV} \qquad (5)$$

The final BEF regression equation is:

$$BEF = 1.6935 \times 0.9939^{BV} \qquad (6)$$

where

BEF = biomass expansion factor in t ha^{-1}

BV = biomass inventoried volume in t ha^{-1}

Table 1. Regression coefficients of BV and constant

Model	Coefficients	P > [t]	R^2	Adjusted R^2	RMSE
BEF			0.9965	0.9964	.0502
Constant	1.6935	0.000			
BV	0.9939	0.000			

The P >|t| value of the coefficients was highly significant at 0.01 level which indicates that BV in the regression equation have significant effects in the BEF variation. Change in values in the BV in the model caused changes in the BEF values exponentially.

The coefficient of determination shows that about 99.65% of the variation in the BEF was explained by BV. This implies that less than 1% was left unexplained by the BEF equation. The coefficient of determination was high and the BEF equation can be used to predict BEF at a particular geographical location.

Pearson *et al* (2007) had put forward the knowledge that BEF is significantly related to the growing-stock volume for most forest types, generally starting high at low volumes and then declining at an exponential rate to a constant low value at high volumes. This relationship also applies to *A. mangium* relative to the BEF model developed in this study. A similar conclusion was attained by the study of Soares and Tome (2004) that there was a strong relationship of the BEF with age and stand volume with higher BEF values for very young stands. The BEF value was within the range of tropical broadleaf at 2.0 to 9.0 as reported by Makipaa (In Press).

3.2 Aboveground Biomass

The aboveground biomass density of *A. mangium* plantation in Claveria is shown in Table 2. The aboveground biomass per tree of *A. mangium* ranges between 2.05 to 54.13 t ha^{-1} at the poorest site quality (SI = 12) and 4.38 to 86.35 t ha^{-1} at the best site (SI = 24). The mean annual carbon density accumulation at ages 3, 10 and 17 years were 1.64, 4.11 and 4.82 t ha^{-1} yr^{-1}, respectively in poor site. On similar site quality and ages, the predicted biomass accumulation was 2.05, 21.94 and 54.13 t ha^{-1}. The mean carbon density accumulation from 3 to 17 yrs was 4.04 t ha^{-1} yr^{-1}. On the other hand, at best site (SI = 24), the mean annual carbon density accumulation of the

Table 2. Aboveground biomass density of *A. mangium* plantation in Claveria in t ha^{-1} (2 x 2 m)

Age	Site Index (M)													
	12	13	14	15	16	17	18	19	20	21	22	23	24	25
3	2.05	2.28	2.44	2.68	2.83	3.07	3.22	3.45	3.61	3.76	3.99	4.23	4.38	4.61
4	3.69	4.07	4.38	4.69	5.07	5.38	5.68	6.06	6.36	6.74	7.05	7.42	7.72	8.10
5	5.76	6.29	6.82	7.35	7.80	8.32	8.84	9.36	9.88	10.39	10.91	11.42	11.93	12.43
6	8.25	8.99	9.73	10.47	11.13	11.86	12.58	13.30	14.01	14.72	15.50	16.23	16.90	17.59
7	11.20	12.14	13.08	14.08	15.01	15.92	16.90	17.87	18.76	19.72	20.67	21.60	22.54	23.46
8	14.44	15.64	16.83	18.09	19.31	20.46	21.67	22.86	24.05	25.22	26.37	27.51	28.64	29.82
9	18.01	19.52	21.00	22.47	23.98	25.41	26.88	28.33	29.70	31.11	32.50	33.88	35.23	36.56
10	21.94	23.72	25.50	27.26	29.02	30.68	32.38	34.05	35.69	37.36	38.95	40.50	42.08	43.64
11	26.05	28.21	30.26	32.26	34.23	36.22	38.16	40.06	41.92	43.74	45.57	47.32	49.07	50.78
12	30.50	32.86	35.17	37.48	39.73	41.92	44.06	46.19	48.22	50.25	52.22	54.13	56.04	57.85
13	35.05	37.70	40.28	42.84	45.32	47.72	50.05	52.36	54.59	56.75	58.85	60.87	62.87	64.76
14	39.73	42.68	45.47	48.27	50.97	53.53	56.04	58.46	60.83	63.07	65.26	67.41	69.43	71.36
15	44.53	47.67	50.73	53.67	56.53	59.28	61.90	64.45	66.89	69.21	71.43	73.55	75.59	77.53
16	49.31	52.73	55.77	59.06	62.06	64.88	67.59	70.16	72.63	74.97	77.18	79.29	81.26	83.12
17	54.13	57.72	61.07	64.33	67.37	70.27	73.02	75.59	78.02	80.33	82.48	84.47	86.35	88.10

Figure 3 shows the mean annual aboveground carbon density increment at different site quality with the lower value as poor site while the higher value connotes the best site. The results also confirmed the findings of several authors (Hediyanti and Sulistyawati, 2010; Heriansyah, 2005; Matthias and Arain, 2006 and Wachrinat, 2009) that the carbon density increases at an early age and increases at a declining rate as the tree approach maturity. The increase in tree biomass and consequently carbon stocks as the stand age increases was reported by several authors.

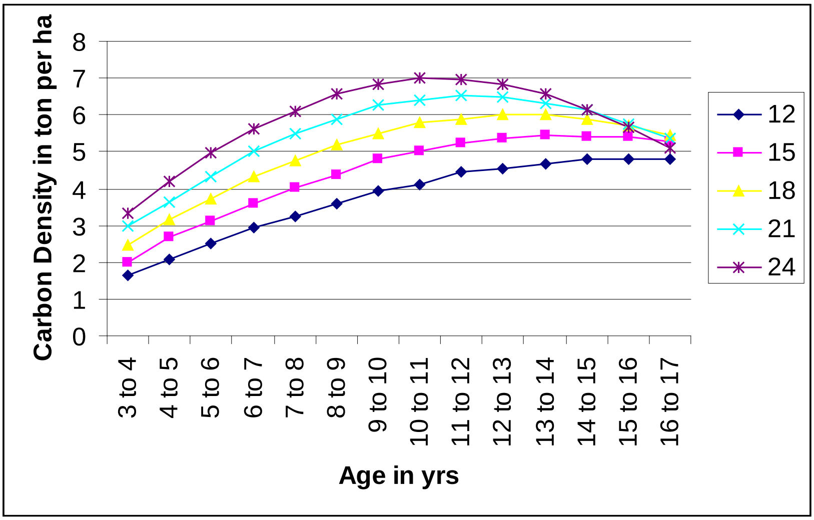


Figure 3. Mean annual aboveground carbon density increment of *A. mangium* at a spacing of 2 m x 2 m at different site indices

The amount of carbon stock accumulated by *A. mangium* from this study is comparable to that of the biomass density of the species in Pantabangan-Caranglan Watershed. At their study site, Lasco*et al.* (2005) found that the level of tree carbon stock (aboveground biomass) was 54.29 t ha^{-1} (using Brown's (1997) allometric equation) and 28.48 t ha^{-1} (Power fit equation). It can also be compared with that of other fast growing species commonly used for agroforestry systems and forest plantations like *A. mangium*, *A. auriculiformis* and *Leucaenaleucocephala*. Hediyanti and Sulistyawati (2010) found that the tree carbon density of 3 yr old plantation of A. mangium was 73.53 t ha^{-1} planted in ParungPanjang, West Java Province, Indonesia.

4. Conclusion and Recommendation

In this study, the aboveground carbon density of *A. mangium* in the smallholder tree plantation was determined using volume over bark, wood density and biomass expansion factor (BEF). The use of BEF is an alternative and non-destructive method of determining carbon density relative to the common allometric equation. The BEF for *A. mangium* supports the general view that there is a strong relationship of the BEF with age and stand volume with higher BEF values for very young stands.

When conducting similar studies in the future, the following recommendations may be very helpful. In any regression analysis, observations and models should be tested first with numerical or graphical regression diagnostic test before proceeding with the analysis. This procedure will significantly contribute to model development processes (i.e. Time, financial resources and many others). This aspect of validation is sometimes overlooked, which resulted in inconsistencies in the model.

The BEF model for *A. mangium* offers an essential aid in the determination of carbon density for *A. mangium* in smallholder plantations in Claveria, Misamis Oriental and for the future management of these land-use systems. There is limited consensus on which smallholder and industrial plantation are more effective in mitigating climate change. This study could shed vital information that will explain the variability in the superiority of sequestering carbon dioxide. Likewise, the result of the study can be an essential aid in the preparation of climate change and carbon density studies pertaining to *A. mangium* and other land-use systems.

This study could fill the information gap on carbon density and carbon sequestration of *A. mangium.*

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