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Allometric Equation and Carbon Sequestration of *Acacia mangium* Willd. in Coal Mining Reclamation Areas

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Abstract

The largest part of carbon exchange (CO_2 and CO) between the atmosphere and the land occurred in the forest because forest vegetation to absorb carbon through photosynthesis to build the other half of woody biomass is carbon compounds. Thus, the status of forest management will determine whether the land acts as a source of emissions (source) or sinks (sinks) of carbon. The amount of organic matter stored in forest biomass per unit area and per unit time is the subject of forest productivity. Forest productivity is a picture of the ability of forests to reduce CO_2 emissions in the atmosphere through physiological activity. Measuring productivity of forests in the context of this study is relevant to biomass measurements. Forest biomass provides important information in the assumed magnitude of potential CO_2 sequestration and biomass in a certain age that can be use to estimate forest productivity.

Tree biomass accumulations and age-related changes of *A. mangium* plantations were determined using a destructive sampling technique. These data were used to estimate optimum harvesting time. Tree biomass samples were collected in 3, 5, and 7 year old plantations in mined area, and in 7 year old plantations in not mined area.

Allometric equations were developed for each site to estimate root, stem, branch, leaf, aboveground and total biomass and stem volume. Using these equations, the stem volume and biomass of each component for each stand age were estimated. A single allometric relationship for all sites was found just for estimation of biomass and stem volume. Allometric expressions of diameter breast height and stem volume for *A.mangium* stand is $Y = 0,000004\ X^{2.7126}$ $R^2 = 0.9838$; and the relationship beetween diameter breast height with tree biomass for *A.mangium*, where allometric equation for stem is $Y = 0.4668\ X^{1.8287}$ with correlation coefficient (R^2) = 0.9855. For the branches is $Y = 0.078\ X^{2.0038}$, with correlation coefficient (R^2) = 0.9542 , and for the leaf is $Y = 0.0648\ X^{1.9348}$ with correlation coefficient (R^2) = 0.9502. The contribution of stem, branch and leaf biomass of *A.mangium* were 67%, 19% and 14% repectively.

Keywords: reclamation, coal minning, carbon sequestration, mulawarman university, allometric, CO_2

1. Introduction

The Earth's atmosphere contains carbon dioxide (CO_2) and other greenhouse gases (GHGs) that act as a protective layer, causing the planet to be warmer than it would otherwise be. If the level of CO_2 rises, mean global temperatures are also expected to rise as increasing amounts of solar radiation are trapped inside the "greenhouse". The level of CO_2in the atmosphere is determined by a continuous flow among the stores of carbon in the atmosphere, the ocean, the earth's biological systems, and its geological materials. As long as the amount of carbon flowing into the atmosphere (as CO_2) and out (in the form of plant material and dissolved carbon) are in balance, the level of carbon in the atmosphere remains constant. (Robert N. Stavins, Kenneth R . Richards ,2005).

The trees act as major CO_2 sink which captures carbon from the atmosphere and acts as sink, stores the same in the form of fixed biomass during the growth process. Therefore growing trees in urban areas can be a potential contributor in reducing the concentration of CO_2 in atmosphere by its accumulation in the form of biomass. As trees grow and their biomass increases, they absorb carbon from the atmosphere and store it the plant tissues (Mathews et. al., 2000) resulting in growth of different parts. Active absorption of CO_2, from the atmosphere in photosynthetic process and its subsequent storage in the biomass of growing trees or plants is the carbon storage (Baes et al., 1977).

In terms of atmospheric carbon reduction, trees in urban areas offer the double benefit of direct carbon storage and stability of natural ecosystem with increased recycling of nutrient along with maintenance of climatic conditions by the biogeochemical processes. (B. L. Chavan, G. B. Rasal, 2010),

Afforestation and reforestation are very prospective forestry project under the clean development mechanism of Kyoto Protocol. Tree growth by CO fixation through photosynthesis process can decrease concentration of CO gases in atmosphere. This is very important provision of the Kyoto protocol, in which developing countries with tropical rain forest are to be involved in an effort to decrease carbon emission through the development of carbon sink, biodiversity, and sustainable forest management. Therefore, estimating carbon sequestration in planted forests is very important activity within global warming issues. (Onrizal, Cecep Kusmana, et.al, 2007)

Acacia mangium Willd., also known as mangium, is one of the most widely used fast-growing tree species in plantation forestry programmes throughout Asia and the Pacific. Its desirable properties include rapid growth, good wood quality and tolerance of a wide range of soils and environments (National Research Council 1983). The recent pressure on natural forest ecosystems in Indonesia inevitably resulted in the use of fast-growing plantation trees, including *A. mangium*, as a substitute to sustain the commercial supply of tree products. Based on trials of 46 species conducted by the Indonesian Ministry of Forestry in Subanjeriji (South Sumatra), *A. mangium* was chosen as the most suitable plantation species for marginal sites, such as alang-alang grasslands (Arisman 2002, 2003). Indonesia has 67% of the total reported area of *A. mangium* plantations in the world (FAO 2002). Rimbawanto (2002) and Barry et al. (2004) reported that around 80% of plantations in Indonesia managed by state and private companies are composed of *A. mangium*. Around 1.3 million ha of *A. mangium* plantations have been established in Indonesia for pulpwood production (Ministry of Forestry 2003). Smallholders also plant A. mangium. According to the Ministry of Forestry and the National Statistics Agency (2004), Central Java and East Java have the highest number of *A. mangium* trees planted by smallholders, with these provinces accounting for more than 40% of the total number of *A. mangium* trees planted by households in Indonesia

2. Material and Methods

2.1.Study Sites

The study was conducted during March to Oktober, 2009 in *A. mangium* plantations in coal mining concession area of "Multi Sarana Avindo Coal Mining Company", East Kalimantan, Indonesia. Field surveys in were conducted in four *A.mangium* plantation sites with stand ages of 3, 5, and 7 years (three plots in mined areas and one plot in not mined area).

The area is locate at longitude 117^{O}.03'55" East and latitude 0^{O}.37'30" South and at elevation 40 – 50 m above sea level (asl), where the annual rainfall is 2.000 mm and annual temperature range between $25^{O}C$ – $33^{O}C$. The soil is a red-yellow podsol and the terrain is flat to undulating. (Ilyas, S, 2012)

2.2.Plot Setting

Three plots (20 × 30 m) for each stand age were established to evaluate tree growth characteristics and to estimate forest biomass. Stem diameter at breast height (D; 1.3 m above ground) and tree height (H) were measured for all *A. mangium* trees in the plot. D was measured using callipers for trees with small D or a diameter tape for trees with large D. H was measured using an ultrasonic hypsometer for heights > 12 m and a measuring rod for heights < 12 m.

2.3.Estimation of Tree Biomass

To formulate allometric equations for trees, about 10 different D-sized (trees > 2 cm in diameter) trees were cut down around the plots.

In total, 12 trees were sampled. After felling and completely unearthing the root system, a sample tree was separated into each component as logs: 0–0.3 m, 0.3–1.3 m, 1.3–3.3 m, etc. every 2 m to the top, and was divided into living branches and twigs, dead branches and twigs, leaves and roots. Tree height, diameter of the logs and weight of tree components of the sample trees were measured in the field. Sub-samples were brought to the laboratory to record the oven-dry weight. Fresh samples were dried at 105°C in a constant- temperature oven. Drying of leaves and wood biomass < 10 cm in diameter required two days, whereas wood biomass > 10 cm diameter required four days. Ratios of dry / fresh mass were calculated and used to convert fresh mass into dry mass.

2.4. Data analysis

In this study, allometric equations to estimate tree component biomass and stem volume of *A.mangium* plantations at each site were established using D and H. We devised equations applicable to each individual stand using the following allometric relationship: $Wi = a (D^2H)^b$; where a and b are constants, D is tree diameter at breast height (cm), H is tree height (m), and Wi is the amount of biomass of component i (kg) or stem volume (m^3). The aboveground biomass was determined by calculating the sum of the biomass of the stem, branch and leaf. Total biomass was calculated as the sum of aboveground biomass and root biomass (Heriansyah, et. al.2007).The total biomass in each plot was calculated from the summed biomass of all trees in the plots. These data were converted into hectares. (Ilyas, S, 2012)

3. Result and Discussion

3.1. Stand properties

Based on forest inventory, the general properties of planted *A.mangium* forests in each study site are shown in Table 1. The stand density is same 1,100 stem ha^{-1}. The basal area and DBH are trend increased from lower stand age into upper stand age.

Table 1. Stand Properties of *A.mangium* on Mined Areas aand Not Mined Areas.

Stand age (years)	Mean Diameter (cm)	Mean Heigth (m)	Volume ha^{-1} ($m^{3)}$)	Stand Density ha^{-1} stem	Bassal Area ha^{-1} ($m^{2)}$)	MAI ($m^{3)}$)	Remark
7*	24.19	8.0	252.24	1,100	48.54	36.03	not mined
7**	17.66	7.0	122.83	1,100	27.85	16.12	mined area
5**	15.28	6.0	85.10	1,100	21.54	17.02	mined area
3**	12.73	5.0	52.31	1,100	14.40	17.44	mined area

*= not mined area; ** =mined area; MAI = Mean Annual Increment

There is a real difference between standing on the areas not mined area by the mined area. From the data obtained shows that the volume per hectare in age 7 years, the area was not mined 252.24 m^3ha^{-1} whereas the former mining areas only 122.83 m^3ha^{-1}. If calculated MAI in areas not mined is 36.03 m^3ha^{-1} while the MAI for mined areas is 16.12 m^3ha^{-1}. Volume per hectare or MAI in not mined areas much bigger than the mined areas. This occurs because the soil conditions at the mined area has changed, which mined areas of land already degraded.

3.2. Allometric Equation

Allometric expressions of diameter breast height and stem volume for *A.mangium* stand with allometric relationship $Y = a X^b$ is $Y = 0{,}000004 X^{2.7126}$ $R^2 = 0.9838$; X is predictor variable (DBH), a is Y intercept, and b is regression coefficient. The graph of allometric expression of that equation presented in Figure 1.

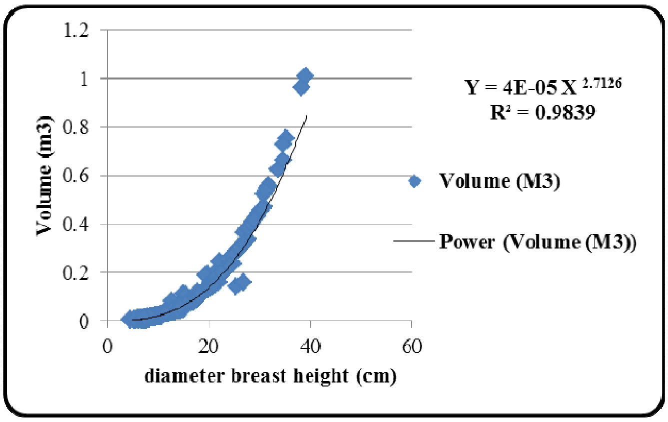

Fig. 1. Allometric equation the relatioship between volume and diameter breast height stand *of A.mangium*

3.3. Biomass in Revegetation Area

Estimating tree and forest biomass is essential for assessing ecosystem yield and carbon stock in compliance with the Kyoto Protocol on greenhouse gas reduction (Brown, 2002; Ko¨rner, 2005). Because measuring tree biomass in the field is extremely time consuming and potentially limited to a small tree sample size, empirical relationships have been use to estimate total biomass from predictive biometric variables such as breast-height diameter (D) or height (H) (Curtis, 1967; Loetsch and Haller, 1973; Wirth et al., 2004). Generally, these empirical relationships are analytically represented as power functions because it has long been noted that a growing plant maintains the proportions between different parts. This function assumes the following form (Niklas, 1994; Kaitaniemi, 2004): $Y = a X^{b}$ with Y total aboveground dry tree biomass, X the diameter at breast-height and a and b is the scaling coefficient and scaling exponent, respectively.

The relationship beetween diameter breast height with tree biomass for *A.mangium*, where allometric equation for stem is $Y = 0.4668 X^{1.8287}$ with correlation coefficient (R^2) = 0.9855. For the branches is $Y = 0.078 X^{2.0038}$, with correlation coefficient (R^2) = 0.9542 , and for the leaf is $Y = 0.0648 X^{1.9348}$ with correlation coefficient (R^2) = 0.9502. The graph of allometric expression of that presented in Fig.2.

The contribution of stem, branch and leaf biomass of *A.mangium* were 67%, 19% and 14% repectively.

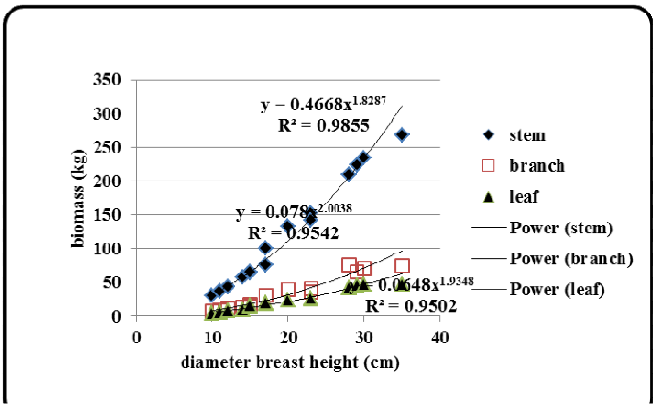

Fig. 2. Allometric equation the relatioship between biomass and diameter breast height stand *of A.mangium*

The biomass storage in different component and stand ages of *A.mangium* tree is shown in Table 2.

Table 2. Biomass storage in different component and stand age of *A.mangium*

Age Class (year)	Volume ha^{-1} (m^3)	Bassal Area ha^{-1} (m^2)	Biomass Stem	Biomass Branch	Biomass Leaf	Total
			Mg ha^{-1}			
7*	252.24	48.54	165.69	48.8	32.42	246.91
7**	112.83	27.85	101.32	27.96	19.05	148.33
5**	85.10	21.54	78.53	21.62	14.75	114.90
3**	52.31	14.40	53.57	14.45	9.94	77.96

*= not mined area; **=mined area

3.4. Root Biomass

Estimates of aboveground biomass based on well-established methods are relatively abundant; estimates of root biomass based on standard methods are much less common. The goal of this work was to determine if a reliable method to estimate root biomass density for forests could be developed based on existing data from the literature. The forestry literature containing root biomass measurements was reviewed and summarized and relation-ships between both root biomass density (Mg ha^{-1}) and root shoot ratios (R/S) as dependent variables and various edaphic and climatic independent variables, singly and in combination, were statistically tested. None of the tested independent variables of aboveground biomass density, latitude, temperature, precipitation, temperature, precipitation ratios, tree type, soil texture, and age had important explanatory value for R/S. However, linear regression analysis showed that aboveground biomass density, age, and latitudinal category were the most important predictors of root biomass density, and together explained 84% of the variation. Cairns,M.A et. al.,1997).

Equation for estimates of root biomass (root biomass density) include equations composed by (Cairn et all. 1997) in Sutaryo, D.(2009) is RBD = exp(-1.0587 + 0.8836 x ln AGB). RBD = root biomass density (Mg ha-1), AGB = Above Ground Biomass.

Root biomass estimates are bassed on total of AGB are presented in Table 3.

Table 3. Root biomass and total tree biomass *A. mangium*

Age (years)	Biomass					
	Stem	Branch	Leaf	AGB	Root	Total
	(Mg.ha^{-1})					
7*	165.69	48.80	32.42	246.91	45.11	292.02
7**	101.32	27.96	19.05	148.33	28.75	177.08
5**	78.53	21.62	14.75	114.90	22.95	137.85
3**	53.57	14.45	9.94	77.96	16.29	94.25

*=not mined area; ** = mined area; AGB = Above Ground Biomass

3.5. Carbon Content and Sequestration of CO_2

Carbon dioxide (CO_2) in the atmosphere is necessary for plants and trees to grow. Forests play a specific and important role in the global carbon cycle by absorbing carbon dioxide during photosynthesis, storing carbon above and belowground and producing oxygen as a by-product of photosynthesis. In the presence of increased greenhouse gases in the atmosphere, forests become even more vital by removing CO_2 from the atmosphere to mitigate the effects of climate change on the environment. Reestablishing trees on previous forestland is a specific type of management. By maintaining areas as forest, trees will continue to sequester carbon. Slight changes in forest management practices can improve the ability of forests to store carbon while still providing other benefits. Extending the time between harvests, encouraging fast-growing species, and fertilization are a few examples of management techniques that could be used to improve forest carbon sequestration. Consequently, the amount of carbon sequestered can be inferred from the biomass change since 50% of the forest dry biomass can be inferred as carbon (Losi et al., 2003; Montagnini and Porras, 1998; Montagu et al., 2005) in (Irvin, K et. al., 2012) Carbon content for each tree component and total CO_2 absorp by plants of each component type are presented in Table 4.

Table 4. Total carbon sequestration by *A.mangium* result of revegetation

Stand Class Age (years)	Biomass			Co_2 Absorption		
	AGB	Root	Total	AGB	Root	Total
	Mg ha-$^{1.}$					
7*	246.91	45.11	292.02	123.46	22.55	146.01
7**	148.33	28.75	177.08	74.16	14.38	88.54
5**	114.90	22.95	137.85	57.45	11.47	68.92
3**	77.96	16.29	94.25	38.98	8.14	47.12

*=not mined area; **=mined area; AGB =Above Ground Biomass

Table 4. shows an increase in carbon absorption as the increasing of stand age. The most defensible options for managing forests for their carbon storage are keeping forests as forests, reforesting areas where forests historically occurred, using forest biomass to offset fossil-fuel use (burning forest biomass generally means that fossil fuel will not be burned), and promoting long-lived forest products such as wood-framed buildings. Forests (particularly older forests) generally store carbon better than forest products, so harvesting old-growth forests for their forest products is not an effective carbon conservation strategy (Harmon et al. 1990) in (Michael G. Ryan, 2012). However, harvest and regeneration of young to middle-aged forests for long-lived forest products can help with carbon storage. In forests with an ecological history of surface and mixed-severity fires, managing for maximum carbon storage will lead to an increase in stand density and the probability of more severe fires. In contrast, managing to reduce fuels and crown fire probability will reduce the carbon stored in the forest and likely be a carbon source unless the thinnings are used for biomass fuel.(Michael G. Ryan, 2012).

4. Conclusion

Based on the results of investigation, the allometric equations suitable for estimating the biomass and carbon stock of stand *A.mangium* forests. Aboveground biomass and carbon stock of planted *A.mangium* forests shows a very significant relation with diameter at breast height (DBH) which forms a logarithmic function. The best allometric equations for above ground biomass and carbon stock of planted *A.mangium* were The relationship beetween diameter breast height with tree biomass for *A.mangium*, where allometric equation for stem is $Y = 0.4668\ X^{1.8287}$ with correlation coefficient (R^2) = 0.9855. For the branches is $Y = 0.078\ X^{2.0038}$, with correlation coefficient (R^2) = 0.9542 , and for the leaf is $Y = 0.0648\ X^{1.9348}$ with correlation coefficient (R^2) = 0.9502. The amount of CO_2 uptake by plants depends on the age of the plant, and where the growth of rate of fertility. Total uptake of CO_2 by *A.mangium* at age 7 years for not mined area is 146,01 Mg ha^{-1}, for mined area at age 7,5,3 is 88.54 Mg ha^{-1}, 68.92 Mg ha^{-1} and 47.12 Mg ha^{-1}, respectively.

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Fig. 3. Location of Study Area in East Kalimantan, Indonesia.