Allometric biomass and carbon stock equations of planted *Eucalyptus grandis* in Toba Plateau, North Sumatra

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Abstract

Estimating carbon sequestration in planted forests is very important activity within global warming issues. The main objective of our research was to develop allometric equation of aboveground biomass and carbon stock of planted *Eucalyptus grandis* forests in Toba plateau, North Sumatra using destructive method. The 18 tress of *E. grandis* was cutting to formulate allometric equation both aboveground biomass and carbon stock of 1-to-9 year old *E. grandis* trees. The variables observe include biomass and carbon content for individual stem, branch, and leaf for aboveground biomass and carbon stock. Organic carbon content from each part of *E. grandis* trees was analyzed by CN analyzer in laboratory. The result showed that allometric equation both biomass and carbon stock was in good relation with stem diameter (D) as log-linear equation. Carbon content average of *E. grandis* tree part was 44.92%. The best allometric equations for aboveground biomass and carbon stock of planted *E. grandis* were $W_{AG} = 0.0678D^{2.5794}$ (R^2 98.8%) and $C_{AG} = 0.0266D^{2.6470}$ (R^2 98.0%), respectively.

Keywords: allometric, biomass, carbon stock, *Eucalyptus grandis*, Toba plateau, North Sumatra

Introduction

Current global circulation models from NAST (2000) predict that average annual global surface air temperatures may increase by approximately 2.5°C by the end of this century. Much of the increase in air temperature has been attributed to the increase in atmospheric carbon dioxide (CO_2) over the past 100 years (NAST, 2000).

In the global warming issues, carbon absorption by forest ecosystem receives considerable attention now (Komiyama et al. 2005). Forests form both natural and plantation forests, a major component of the carbon reserves in the world's ecosystem (Whittaker and Linkens, 1975) and greatly influence the lives of other organism as well as human societies (Komiyama et al., 2008).

Afforestation and reforestation are very prospective forestry project under the clean development mechanism of Kyoto Protocol. Tree growth by CO_2 fixation through photosynthesis process can decrease concentration of CO_2 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.

Eucalyptus grandis W. Hill ex Maiden has been an important and a major species in plantation forests in Toba plateau, North Sumatra since the beginning 1990. The planted

E. grandis forests in Toba highland are managed by PT Toba Pulp Lestari Tbk (PT TPL) as raw material for pulping industry. The main objective of our research was to develop allometric equation of aboveground biomass and carbon stock of planted *Eucalyptus grandis* forests in Toba plateau, North Sumatra.

Material and Method

Research site and period

Field research was carried out during May - July 2006 at Tele Sector as a part of PT TPL planted forest concession. The sites are at an elevation from 1,600 to 1,700 m above sea level. PT TPL (2006) reported that the mean of annual rainfall was 1,002.2 mm in period of 2005-2006. The minimum of monthly rainfall during this period was 23.2 mm in May, and the maximum was 166.3 mm in July (Fig. 1).

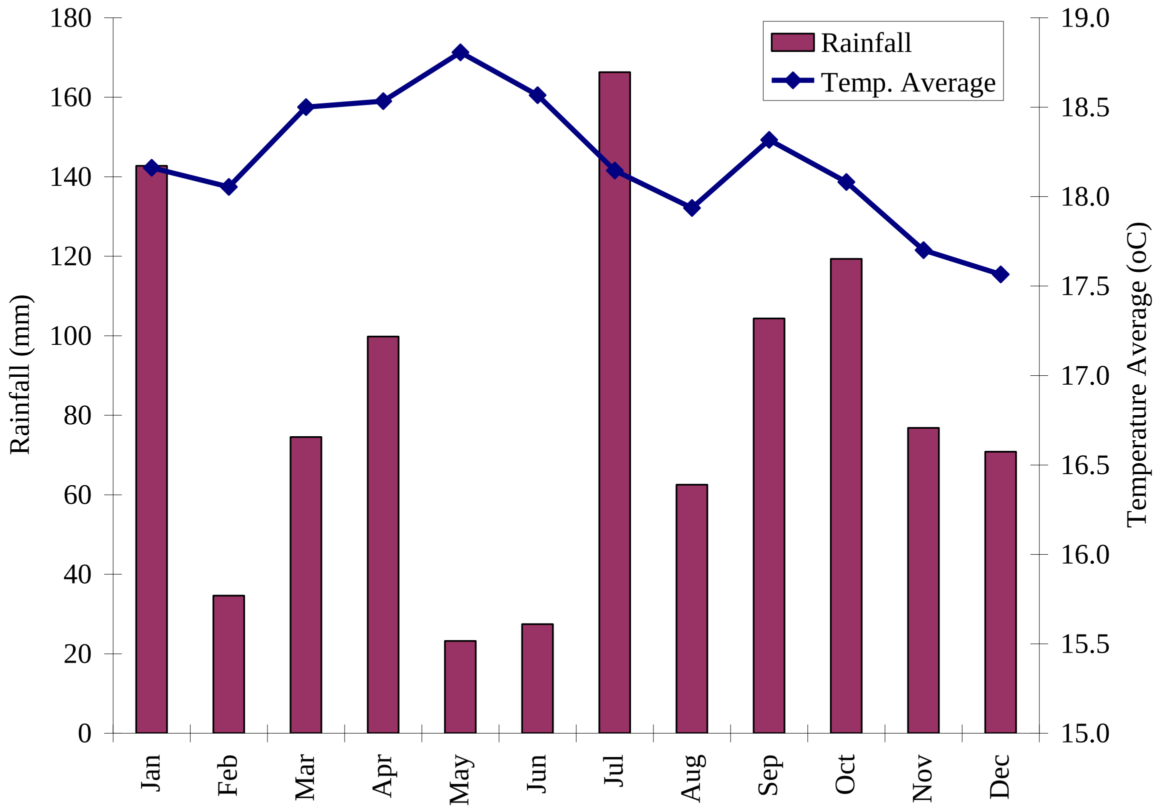

Figure 1. Distribution of monthly precipitation and air temperature in study site

Sampling procedure

We selected six study sites of planted *E. grandis* forests at different stand ages (1-, 2-, 3-, 6-, 8-, and 9-year-old stands) in Tele Sector of PT TPL concession, Toba plateau, North Sumatra (Table 1). In each study site, 10 sub-plots (10 x 10 m) were established based on Heriyanto *et al*. (2002). For each sub-plot, we measured the DBH (stem diameter at 1.3m height) and tree height of all trees.

After tree inventory, totally 18 trees were cut using clipping techniques based on stratified random sampling with diameter class as the basis of stratification. The stem of the sample cut trees was divided into horizons of 1 m long. From each horizon, a fresh weight of each morphological tree compartment, i.e. stem, branch, leaf, and flower and fruit, were separately weighed. According to Kusmana *et al*. (1992) and Heriyanto *et al*. (2002), a small amount sample of each tree compartment was taken and dried in an oven at 80^{o}C for 48 hours to obtain the constant dry weight. Carbon content of each tree compartment was analyzed by CN analyzer.

Table 1. Site code, stand age, planting period and geographic position of each study site of planted *Eucalyptus grandis* forests stand in North Sumatra

Site Code	Age Stand (year)	Planting Period	Geographic Position
Bloc P01 02700Z	1	Feb 2005	2^{0}25'03"N; 98^{0}36'25"E
Bloc P01 02504Z	2	May 2004	2^{0}25'10"N; 98^{0}36'00"E
Bloc P01 01803Z	3	Sep 2003	2^{0}25'48"N; 98^{0}36'16"E
Bloc T09 01800Z	6	Jan 2000	2^{0}30'45"N; 98^{0}37'09"E
Bloc D01 00501Z	8	Sep 1998	2^{0}27'04"N; 98^{0}37'12"E
Bloc D01 01800Z	9	Apr 1997	2^{0}26'02"N; 98^{0}36'50"E

Data analyses

In terms of aboveground tree biomass and carbon were estimated using simple allometric equation in the form of:

$$Y = aX^b$$

where Y is dry weight or carbon of tree components, X is predictor variable (DBH), a is Y intercept, and b is regression coefficient.

Result and Discussion

Stand properties

Based on forest inventory, the general properties of planted *E. grandis* forests in each study site are shown in Table 2. The stand density is varying from 534 (6-year-old stand) to 1,390 stem/ha (2-year-old stand). The stand basal area and DBH are trend increased from lower stand age into upper stand age.

Table 2. General properties of planted *Eucalyptus grandis* forests in North Sumatra

No	Planting Year	Stand Age (Year)	Stand Density (stem/ha)	BA (m^2/ha)	DBH (cm)	H (m)
1.	2005	1	790	3.57	4.49 ± 1.70	4.42 ± 1.27
2.	2004	2	1,390	23.17	8.75 ± 2.90	8.71 ± 2.41
3.	2003	3	1,100	28.32	11.13 ± 2.72	12.64 ± 2.30
4.	2000	6	534	19.46	11.87 ± 6.81	8.87 ± 5.02
5.	1998	8	940	43.78	14.24 ± 5.91	14.80 ± 5.18
6.	1997	9	1,090	66.94	16.89 ± 5.30	19.75 ± 4.35

Remarks: BA = basal area; DBH = diameter at breast height; H = tree height;

Allometric biomass and carbon stock equation

Allometric expressions of each above-ground morphological tree compartment both biomass and carbon stock follows logarithmic function with high correlation. Allometric biomass equations of aboveground morphological tree compartment of *E. grandis* are shown at Table 3. Based on the selected allometric equations (Table 3), above – ground biomass of each tree morphological compartment can be measured.

Calculations revealed that the total aboveground biomass of planted *E. grandis* forests in the research site amounts to 129.84 t/ha and 81.89 t/ha at 9- and 8-year-old stand.

Based on carbon content analyses by CN Analyzer, we know that average of carbon content of *E. grandis tree* part was 44.92% of biomass with varying from 36.72 to 54.01% of biomass. Allometric carbon stock equations of aboveground morphological tree compartment of *E. grandis* are shown at Table 4. Based on the selected alometric carbon stock equation (Table 4), the total of aboveground carbon stock of planted *E. grandis* was estimated amounts to 62.84 t C/ha and 39.43 t C/ha at 9- and 8-year-old stand.

Table 3. Allometric biomass coefficient ($W_n = a*DBH^b$) of every tree-parts of planted *Eucalyptus grandis* forests in North Sumatra

No.	Tree part	Coefficient		R^2	R_a^2
		a	B	(%)	(%)
1.	Stem	0.0436	2.6883	98.28	98.17
2.	Branch	0.0228	2.0779	82.03	80.90
3.	Leaf	0.5775	0.6549	31.73	27.47
4.	Aboveground	0.0678	2.5794	98.80	98.73

Table 4. Allometric carbon stock coefficient ($C_n = a*DBH^b$) of every tree-parts of planted *Eucalyptus grandis* forests in North Sumatra

No.	Tree part	Coefficient		R^2	R_a^2
		a	*b*	(%)	(%)
1.	Stem	0.0176	2.7511	97.40	97.24
2.	Brach	0.0097	2.0848	83.66	82.64
3.	Leaf	0.2167	0.7199	35.08	31.02
4.	Aboveground	0.0266	2.6470	98.04	97.92

Table 5 shows the allometric coefficient which were calculated from the allometric relations between the biomass of various tree compartments on tree diameter (*DBH*) for some tree species in tropical region. Comparison of planted *E. grandis* forests stand's allometric coefficients obtained with those reported for some trees shows that the allometric coefficient "b" of total above-ground biomass for planted *E. grandis* forests stand in study area was comparable to that tropical tree species, such as general tropical tree species, rubber tree (*Hevea brasiliensis*), and non-rubber tree in the tropic.

Comparing aboveground biomass (ABG) of planted *E. grandis* in Toba plateau, North Sumatra with other planted forest (Table 6), we know that the ABG of planted *E. grandis* was larger than the planted forest in tropical and temperate region. It means that the planted *E. grandis* forest is potential activity to carbon sequestration in the tropical highland.

Table 5 The allometric coefficient of aboveground morphological compartment biomass on *DBH* for some tree species in tropical region

Tree Species	Coefficient*		R^2	Source
	A	b		
1. General tropical tree species	0.118	2.53	97.0	Brown (1997)
2. Rubber tree (*H. brasiliensis*)	0.095	2.62	99.6	Pamoengkas *et al*. (2000)
3. Non-rubber tree	0.091	2.59	99.6	Pamoengkas *et al*. (2000)
4. *E. grandis*	0.0678	2.579	98.8	This study

*Allometric coefficients were calculated from the allometric equation $W_x = a*DBH^b$

Conclusion

Based on our results, we were able to provide allometric equations suitable for estimating the biomass and carbon stock of planted *E. grandis* forests. Aboveground biomass and carbon stock of planted *E. grandis* forests shows a very significant relation with diameter at breast height (DBH) which forms a logarithmic function. The best allometric equations for aboveground biomass and carbon stock of planted *E. grandis* forests were $W_{AG} = 0.0678D^{2.5794}$ (R^2 98.8%) and $C_{AG} = 0.0266D^{2.6470}$ (R^2 98.0%), respectively.

Tabel 6. Aboveground biomass (ABG) of some species of tropical and temperate planted forest

Tree Species	Site	Stand age (year)	Stand density (stem/ha)	AGB (t/ha)	Source*
Acacia	Maribaya, West Java	10	225	69.73	1
mangium	Madang, PNG	7	506	109.20	2
	Sobne, Vietnam	6	1,289	121.10	3
P. sylvestris	Finlandia	100	td	121.30	4
E. grandis	Sumatera Utara	9	1,090	129.52	5

Source*: 1 = Heriansyah et al. (2003), 2 = Yamada et al. (2000a), 3 = Yamada et al. (2000b), 4 = Helmisaari et al (2002), 5 = this study

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