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Carbon Sequestration and Clean Development Mechanism

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A GENERAL ALLOMETRIC EQUATION FOR ESTIMATING BIOMASS IN *ACACIA MANGIUM* PLANTATIONS

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ABSTRACT

Acacia mangium Willd. is one of the most important tree species grown in commercial plantations in Monsoon Asia. Recently, the need for accurate information on the biomass in plantations has become more urgent, especially since the amount of carbon sequestered in afforestation/reforestation Clean Development Mechanism (AR-CDM) projects in developing countries can be included under the Kyoto Protocol. We present here a general allometric equation for estimating aboveground biomass (AGB) of *A. mangium* plantations from the diameter of the trees recorded at the respective sites. Destructive samplings were conducted in plantations in Papua New Guinea (PNG), Vietnam, and Indonesia. At each site, 4-12 trees were felled, their trunks, branches and leaves were separately weighed, and allometric models for estimating AGB was determined. A general allometric equation (a log-log model) was developed from an overall total of 26 sample trees from the sampled sites. No significant differences were found between the biomass estimations derived from the site-specific and the general allometric equations. The general allometric equation may allow us to estimate AGB of *A. mangium* plantations in Monsoon Asia without destructive sampling.

INTRODUCTION

Plantations of fast-growing species have been rapidly increasing in Monsoon Asia in recent years, especially since about 1990 (Cossalter and Pye-Smith 2003). As part of this trend, plantations of *Acacia mangium* have been established at many secondary forest and grassland sites across the region. Such plantations covered about 20×10^6 ha (ca. 9.4% of the total forested area) in ASEAN countries in the year 2000 (FAO 2003). Evaluating biomass is important for effective management of plantations to achieve economic goals, especially for generating high returns in short periods. Another reason for evaluating biomass, which has become important recently, is for estimating the amount of carbon sequestered in afforestation/reforestation Clean Development Mechanism (AR-CDM) project that can be included under the Kyoto Protocol.

Biomass data related to specific *A. mangium* plantations have been gathered by many researchers (Diana et al. 2002; Hardyanto et al. 1999; Heriansyah et al. 2003; Morikawa et al. 2001, 2002; Tanouchi et al. 1994; Tsai and Hamzah 1985; Yamada et al., in press) and this information is obviously important for each respective site. However, estimating biomass by allometric equations may be time-consuming and laborious, because of the need to fell sample trees at the target research site, and the felling may adversely affect the site. Therefore, there is a clear need to develop methods for estimating the biomass of managed plantations at diverse sites simply with non-destructive methods. We here present one such method in which biomass of almost harvest time (6-8 years) is conveniently estimated from the general allometric equation made by destructive sampling in 4 investigated sites with tree census data acquired at the respective site(s).

STUDY AREAS

Field investigations were carried out at 4 sites in Monsoon Asia: Madang in Papua New Guinea (PNG), Sonbe in Vietnam, Benakat and Bogor in Indonesia (Figure 1).

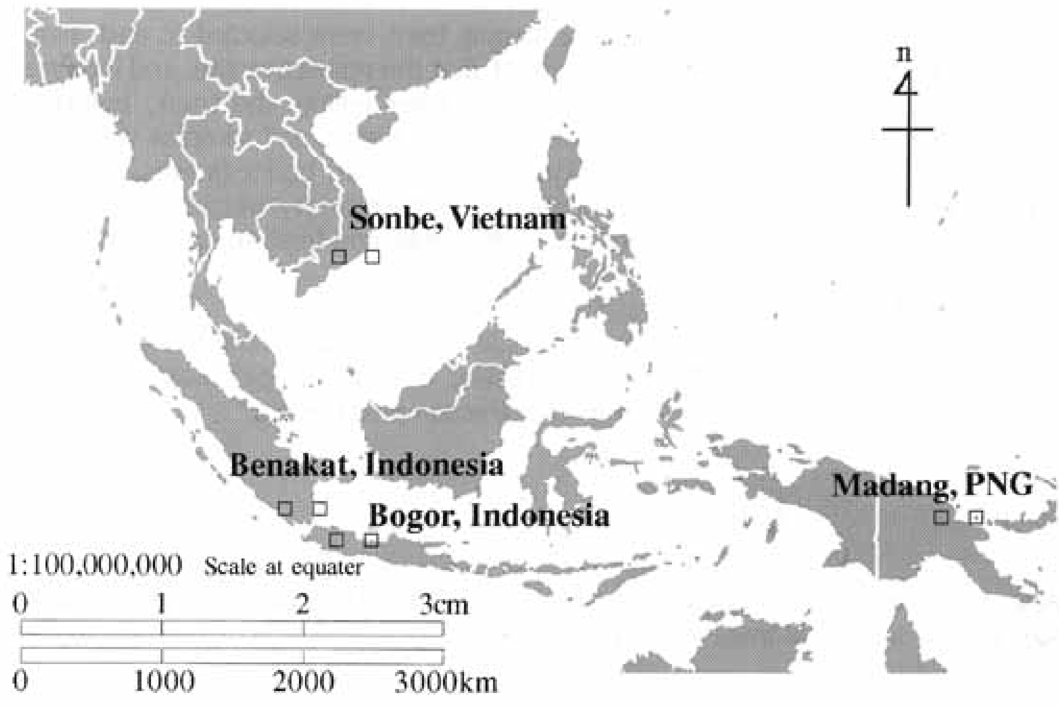


Figure 1. Field investigation sites

Madang, PNG: Field investigations were carried out from late August to early September 1999. Seven-year-old plantation on a flat area was selected. The spacing here was 3.5×3.5m (816n ha^{-1}). For detailed information on this site, see Morikawa et al. (2001).

Sonbe, Vietnam: Field investigations were carried out in late August 1998. Six-year-old plantation on a flat area was selected. The spacing here was 3×3m (1,111n ha^{-1}). For detailed information on this site, see Morikawa et al. (2001).

Benakat, South Sumatra, Indonesia: Field investigations were carried out in early September 2001. Six-year-old plantations with several different spacings of 2.5×4m (1,000n ha^{-1}), 3.5×2m (1,429n ha^{-1}), 3×4m (833n ha^{-1}) and 3.5×3m (952n ha^{-1}) on a flat area were selected. For detailed information on this site, see Hardyanto et al. (1999).

Bogor, West Java, Indonesia: Field investigations were carried out in early August 2001. Four 8-year-old plantations on a flat area were selected. The spacing of all selected plots was 3×3m (1,111n ha^{-1}). For detailed information on this site, see Heriansyah et al. (2003).

METHODS

The trunk diameter at 1.3m high above ground (D) of all trees was measured at each plot. When tree trunks had separated into 2-3 stems at a lower point than this we measured each stem, regarding them all as single trunks.

For calculating allometric equations, 4-12 sample trees were selected at each plot, with consideration for roughly spanning the range of D at the respective site, and intervals that were roughly consistent with the D distribution. After felling, the trunk, branches and leaves of each sample tree were separated and weighed. Small samples were then extracted from each separated organ, weighed, dried for 96 hours (leaves, 48 hours) at 80••, and re-weighed, in order to determine their fresh to dry weight ratios. The biomass of each organ was calculated from the fresh weight and fresh to dry weight ratio thus obtained.

The aboveground biomass (AGB) of each sample tree was summation of biomass of trunk, branches, and leaves. The AGB of no-destructive trees in the plot was estimated from allometric equations relating the AGB to D of the sampled trees:

$$AGB = a(D^2)^b \qquad (1)$$

where a and b are coefficients of the regression function. The AGB of the plot is summation of the AGB of individual trees in the plot.

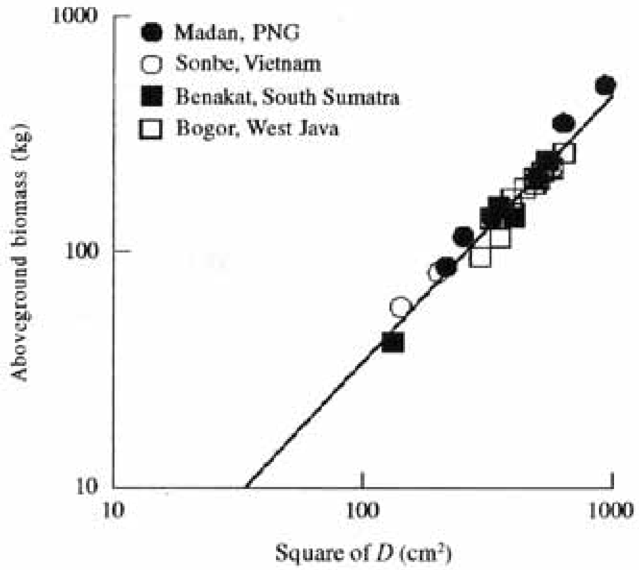
We estimated the AGB of each plantation by two allometric equations (log-log models): a site-specific equation derived for each investigated site, and a general equation derived from 26 sample trees from all four investigated sites, as described above.

RESULTS

Each site-specific equation and the general equation were highly accurate, and the deviations were small. The AGB of individual trees derived from the general equation using the 26 sample trees from the 4 sites indicated that there was high correlation with only minor variation among sites (Figure 2).

$$AGB = 1.876\times10^{-1} D^{1.131} \quad R^2 = 0.951 \quad n = 26 \qquad (2)$$

There were no significant differences between the AGB of the plot calculated by the two equations (p<0.001, X^2 test for goodness of fit) (Figure 3). The difference between the results generated using the site-specific and general equations was 4.1% on average (range, 0.1-13.5%). The values for the Benakat plot (initial density; 833n ha^{-1}) derived from the site-specific and general equations were almost identical: 172.8 and 172.6 Mg ha^{-1}, respectively, while the seven-year-old plantation in Madang gave the largest deviation: 113.2 and 99.7 Mg ha^{-1}, respectively (Table 1).



Figre 2. Allometric relation between square of *D* and AGB of the sampled trees at the four investigated sites

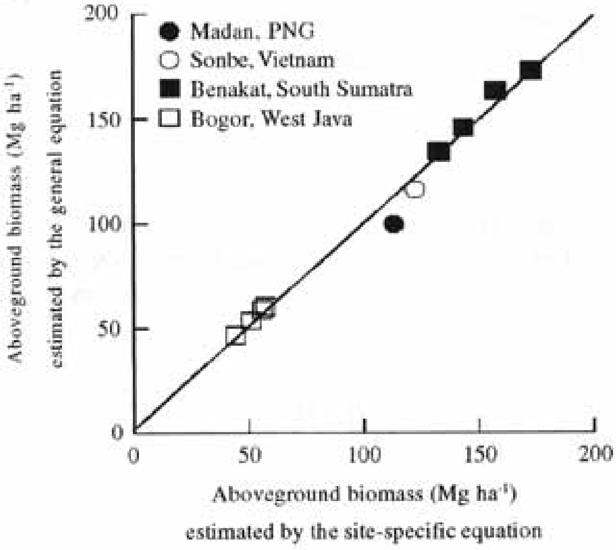


Figure 3. The relation between AGB estimated by the site-specific and general equations at the four investigated sites. The line shows Y=X.

Table 1. Site, measured age, tree density (initial, actual), basal area, the AGB from the site-specific and the general equations, and relative error

Sites (Measured age)	Density: Initial density ($n\ ha^{-1}$)	Density: Actual density ($n\ ha^{-1}$)	Basal area (m^2 ha-1)	AGB: Site-specific equation ($Mg\ ha^{-1}$)	AGB: General equation ($Mg\ ha^{-1}$)	Error associated with model (%)
Madang, PNG (7 years)	816	506	18.4	113.2	99.7	13.5
Sonbe, Vietnam (6 years)	1,111	1289	23.4	122.4	116.1	5.5
Benakat, Indonesia (6 years)	1,000	822	25.5	132.6	134.3	-1.2
Benakat, Indonesia (6 years)	1,429	1369	31.9	157.5	162.9	-3.3
Benakat, Indonesia (6 years)	833	787	25.2	133.2	134.0	-0.6
Benakat, Indonesia (6 years)	952	877	32.1	172.8	172.6	0.1
Benakat, Indonesia (6 years)	1,000	903	27.6	143.5	145.4	-1.3
Bogor, Indonesia (8 years)	1,111	250	8.7	44.2	46.6	-5.2
Bogor, Indonesia (8 years)	1,111	283	10.0	51.0	53.6	-4.8
Bogor, Indonesia (8 years)	1,111	317	11.3	57.2	60.3	-5.2
Bogor, Indonesia (8 years)	1,111	283	10.9	56.1	58.7	-4.5

DISCUSSION

In general, allometric equations for estimating biomass are based on trunk diameter, tree height and plant dry matter (Kato et al. 1978; Yamakura et al. 1986). However, it is often difficult to measure the height of broad-leaved tree species and individual trees in forests with closed canopies. Therefore, allometric equations including tree height are often not suitable or convenient for use in plantations. Furthermore, the accuracy of height information in site census data may be low, even if detailed data are available. The approach developed in this study uses only D as a parameter for the allometric relations, and the allometry based on D is sufficient for predicting biomass. The D is the most commonly used tree parameter for any site, and the most easily measured variable for compiling data on the size of the trees in a specific forest. However, the general allometric equation presented here may only be valid for a limited D range, so we need to check its applicability to trees with both smaller and larger D.

The presented approach should be useful for evaluating the biomass of *A. mangium* plantations at any site because no site-specific differences in calculated values were found. We suggest that biomass differences among sites are not reflected in allometric differences, and trees with both low and high biomasses appear to conform to the general allometric equation (Figure 2).

The results suggest that it is not necessary to cut sample trees at target sites in order to obtain site-specific allometric relationships, since accurate information on biomass can be derived from the general allometric equations presented here relating biomass and tree diameters in *A. mangium* plantations.

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