

ノート (Note)

Allometric equations for bottle-shaped tree (*Ceiba chodatii*) in the Chaco region, western Paraguay

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In western Paraguay, the dry forest is a typical forest type and is characterized by predominant xeromorphic species such as *Aspidosperma quebracho-blanco* (Spichiger et al. 2005). *Ceiba chodatii*, a deciduous tree with a swollen, bottle-shaped trunk, is also a characteristic of the dry forest communities in Paraguay (Gibbs and Semir 2003). We had already developed allometric equations to estimate the tree biomass in the major Paraguayan eco-regions including the dry and humid Chaco regions (Sato et al. 2015). However, our established models are not suitable for

estimating the biomass of the bottle-shaped *Ceiba* tree (Photo 1). In this study, we aimed to develop *Ceiba*-specific biomass estimation models in the dry forests of western Paraguay.

To develop allometric equations, destructive samplings were conducted in Mariscal Estigarribia (21°59'S 60°37'W) and La Patria (21°23'S 61°29'W) in Gobernación de Boquerón. We selected five *Ceiba* trees ranging from 6.4 cm to 107.3 cm diameter at breast height (Table 1). After felling, we measured the tree height (H) with a tape measure and divided the aboveground biomass (AGB) into leaves, branches, and stem. Tree stumps, root with diameter ≥ 2 mm and soil under the tree crown area were excavated with heavy machinery. The stumps were separated into AGB and belowground biomass, each of which was weighed. Furthermore, we calculated the stem volumes by Smalian's formula. We developed allometric models involving two independent variables: D (cm) and H (m) and applied linear models to log-transformed data. Stem volume (V_{stem} ; m³), dry weight of total biomass (Total; kg), and AGB (kg) were dependent variables. Because log-transformed data lead to bias in biomass estimation, back-transformed results were multiplied by a correction factor (Sprugel 1983). Samples were collected in July 2013 at La Patria and in October 2013 at Mariscal Estigarribia. Details of the sampling sites and methods are described in Sato et al. (2015).

Although model 1 had a high coefficient of determination ($r^2 > 0.98$, $P < 0.0001$; Table 2), the inclusion of H (model 2) improved the fit for all three dependent variables. As a result, the best models for *C. chodatii* are:

$$\begin{aligned} V_{\text{stem}} &= 0.000117*(D^2H)^{0.8387} \\ \text{AGB} &= 0.0224*(D^2H)^{0.8688} \\ \text{Total} &= 0.0585*(D^2H)^{0.8151} \end{aligned}$$

Our models represent the first attempt to develop allometric equations, including belowground parts, for *C. chodatii*. Although our sample numbers were limited, the models provide relatively low errors in AGB and total biomass estimation (<5%; Table 2) as compared to the results using the Chaco Seco models developed



Photo 1. Bottle-shaped trunk of *C. chodatii* in Mariscal Estigarribia, Paraguay.

パラグアイ西部チャコ地方に生育する *Ceiba chodatii* のアロメトリ式
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Table 1. Size, dry mass of each component, and stem volume of the sample trees.

Sample ID	DBH (cm)	Height (m)	Dry weight (kg)					Stem volume (m ³)
			Stem	Branch	Leaf	Root	Total	
PA3	6.4	6.1	2.70	0.18	0.01	2.24	5.12	0.0131
ME5	29.0	8.1	39.49	1.96	0.27	32.07	73.79	0.1261
ME6	72.7	8.7	186.11	18.39	0.67	59.33	264.50	0.8510
ME7	107.3	10.8	519.53	201.51	6.29	255.73	983.05	2.5410
ME8	33.7	7.4	48.70	7.17	0.24	47.36	103.47	0.2493

Sample ID code: PA (La Patria); ME (Mariscal Estigarribia)

Table 2. Results of regression analysis for allometric models of *C. chodatii* in western Paraguay.

Model	Equation	a ₀	a ₁	r ²	CF ^a	RSE ^a	AIC ^a	Error(%) ^b
Aboveground biomass (kg)								
Model 1	$\ln(AGB) = a_0 + a_1 \ln(D)$	-2.5627	1.8947	0.987	1.0278	0.234	3.13	4.60
Model 2	$\ln(AGB) = a_0 + a_1 \ln(D^2H)$	-3.8178	0.8688	0.992	1.0170	0.184	0.69	2.88
Chaco Seco Model ^c	$\ln(AGB) = a_0 + a_1 \ln(D^2H)$	-1.5833	0.8391	0.964	1.0457			654.00
Total biomass (kg)								
Model 1	$\ln(Total) = a_0 + a_1 \ln(D)$	-1.6863	1.7779	0.982	1.0343	0.260	4.16	5.84
Model 2	$\ln(Total) = a_0 + a_1 \ln(D^2H)$	-2.8631	0.8151	0.987	1.0254	0.224	2.67	4.33
Chaco Seco Model ^c	$\ln(Total) = a_0 + a_1 \ln(D^2H)$	-1.3360	0.8379	0.968	1.0397			501.09
Stem volume (m ³)								
Model 1	$\ln(V_{stem}) = a_0 + a_1 \ln(D)$	-7.8902	1.8317	0.981	1.0392	0.277	4.80	6.54
Model 2	$\ln(V_{stem}) = a_0 + a_1 \ln(D^2H)$	-9.0929	0.8387	0.982	1.0365	0.268	4.46	6.18

^a CF: correction factor, RSE: residual standard error, AIC: Akaike information criterion.^b Error (%) = 100 × (biomass_{predicted} - biomass_{measured}) / biomass_{measured}^c Chaco Seco Model for *AGB* and *Total* were developed by Sato et al. (2015) excluding *Ceiba* data.

by Sato et al. (2015). Using the *Ceiba* models in combination with the established eco-region models (Sato et al. 2015) could reduce the uncertainty in biomass estimation in Paraguay.

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