「森林総合研究所研究報告」(Bulletin of FFPRI) Vol.14 No.2 (No.435) 75 - 76 June 2015

ノート（Note）

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

Tamotsu SATO[1)*], Masahiro SAITO [2)], Delia RAMÍREZ[3)], Lidia F. PÉREZ DE MOLAS[3)], Jumpei TORIYAMA[1)], Yukako MONDA[1)], Yoshiyuki KIYONO[4)], Emigdio HEREBIA[3)], Edgardo DURÉ VERA[5)], Jorge David RAMIREZ ORTEGA[5)] and Mirtha VERA DE ORTIZ[3)]

Key words: tree biomass, *Ceiba chodatii*, allometric models, semi-arid forests, xeromorphic species

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.

Photo 1. Bottle-shaped trunk of *C. chodatii* in Mariscal Estigarribia, 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}; m^3), 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:

$$V_{stem} = 0.000117*(D^2H)^{0.8387}$$
$$AGB = 0.0224*(D^2H)^{0.8688}$$
$$Total = 0.0585*(D^2H)^{0.8151}$$

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

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
佐藤保、斉藤昌宏、Delia RAMIREZ、Lidia F. PÉREZ DE MOLAS、鳥山淳平、門田有佳子、清野嘉之、Emigdio HEREBIA、Edgardo DURÉ VERA、Jorge David RAMIREZ ORTEGA、Mirtha VERA DE ORTIZ、
Received 17 February 2015, Accepted 4 March 2015
1) Department of Forest Vegetation, Forestry and Forest Products Research Institute (FFPRI)
2) Bureau of Climate Change, FFPRI
3) Facultad de Ciencias Agrarias, Universidad Nacional de Asunción (UNA)
4) Research Coordinator, FFPRI
5) Instituto Forestal Nacional (INFONA)
* Department of Forest Vegetation, FFPRI, 1 Matsunosato, Tsukuba, Ibaraki, 305-8687, Japan; e-mail: satoo@affrc.go.jp
森林総合研究所森林植生研究領域　〒 305-8687 茨城県つくば市松の里 1

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	Leave	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.

We thank Ms. Damiana Mann and the staff of INFONA for coordination in sampling. Field work was assisted by the technical staff of the Centro Forestal Alto Paraná, INFONA. This study was supported by "The emergency project to develop the structure of promoting REDD action" of the Forestry Agency, Ministry of Agriculture, Forestry and Fisheries, Japan.

References

Gibbs, P. and Semir, J. (2003) A taxonomic revision of the genus *Ceiba* Mill. (Bombacaceae). Anales Jard. Bot. Madrid, 60, 259-300.

Sato, T., Saito, M., Ramírez, D., Pérez de Molas, L.F., Toriyama, J., Monda, Y., Kiyono, Y., Herebia, E., Dubie, N., Duré Vera, E., Ramirez Ortega, J.D., and Vera de Ortiz, M. (2015) Development of allometric equations for tree biomass in forest ecosystems in Paraguay. JARQ, 49, 281-291.

Spichiger, R., Calenge, C. and Bise, B. (2005) Discriminant analysis of the spatial distribution of plant species occurrences: II. Distribution of major tree communities in Paraguay. Candollea, 60, 577-593.

Sprugel, D.G. (1983) Correcting for bias in log-transformed allometric equations. Ecology, 64, 209-210.