Allometric Tree Biomass and Volume Models in Tanzania

Edited by Malimbwi R.E., Eid T., and Chamshama S.A.O.

E&D Vision Publishing

The book ***"Allometric Tree Biomass and Volume Models in Tanzania"*** documents biomass and volume models and various processes involved in their development for different vegetation types and some tree species in Tanzania. This book is organized into 14 chapters:

- Chapter 1 is an introductory part which covers forests and forest types in Tanzania and the importance of forest biomass and volume models in Tanzania;
- Chapter 2 gives background information on development of biomass and volume models;
- Chapter 3 is on biomass and volume models for the vast miombo woodlands in Tanzania;
- Chapter 4 provides models for predicting biomass of individual trees in lowland and humid montane forests *(AGB, BGB, twigs and leaves, branches and stem);*
- Chapter 5 presents general and species-specific models for AGB and BGB for three main mangrove species *(Avicennia marina, Rhizophora mucronata and Sonneratia alba);*
- Chapter 6 focuses on AGB and BGB biomass models and total volume models for Itigi thickets of central Tanzania dominated by *Pseudoprosopi fischeri and Combretum celastroides;*
- Chapter 7 is on *Acacia-Commiphora* woodlands biomass and volume models. Site-specific *(AGB and BGB)* and general *(AGB, BGB and stem)* biomass models are presented;
- Chapter 8 is about general and site-specific allometric models for estimating biomass of *Pinus patula;*
- Chapter 9 describes models for predicting biomass and volume of *Tectona grandis.*
- Chapter 10 deals with biomass and volume allometric models for coconut trees *(Cocos nucifera);*
- Chapter 11 presents cashewnut trees *(Anacardium occidentale)* biomass and volume allometric models;
- Chapter 12 is on biomass and volume models of baobab *(Adansonia digitata)*. AGB and total volume allometric models are presented;
- Chapter 13 compares biomass and volume estimates for different vegetation types and forests obtained by applying models presented in this book with corresponding previously published estimates; and
- Chapter 14 expresses concluding remarks.

The book covers useful knowledge for scholars who wish to engage in tree allometric modelling, and expert practicing forestry for the determination of forest stocking levels needed for forest planning and other processes such as forest carbon trading. It is a book of great interest not only for forest experts but also for forestry students undertaking forest resources assessment at different levels.

ISBN: 985 9987 735 74 7

E&D Vision Publishing Limited

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ISBN: 985 9987 735 74 7

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Malimbwi R.E., Eid T. and Chamshama S.A.O
Allometric Tree Biomass and Volume Models in Tanzania
Second Edition, 2018

Cover photo: ©Josiah Zephania Katani

Published on behalf of Department of Forest Resources Assessment and Management by E&D Vision Publishing Ltd
E-mail:info@edvisionpublishing.co.tz
Website: www.edvisionpublishing.co.tz

Designed by: Maliti Design

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Allometric Biomass and Volume Models for Cashewnut Trees

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11.1 Background

Cashewnut trees (*Anacardium occidentale*) are tropical nut crop trees that belong to the family Anacardiaceae, which is known for having a resinous bark and often, caustic oils in leaves, barks and fruits. Cashewnut trees are native of South America, very likely the centre of origin is Brazil (Mitchell and Mori, 1987). They are thought to have been brought to East Africa and India by the Portuguese in the sixteenth century (Johnson, 1973; Ohler, 1979; Behrens, 1998).

Cashewnut trees consist of about 73 genera and 600 species (Nakosone and Paull, 1998). The tree is evergreen, fast growing and reaches a height of 10 - 15 m and often has an irregularly shaped trunk. Farm management practices consist of weeding, pruning and spraying pesticides and fungicides. Cashewnut trees are planted at a spacing of 12 × 12 m making a total of 70 trees per hectare (ha) (UNIDO, 2011). This species has ability to grow on poor soils and can be intercropped with food crops such as maize, cassava and groundnuts. Cashewnuts are consumed as food as well as marketed for export. The crop prefers deep, well drained, light textured soils which facilitate extensive lateral root extension (Martin et al., 1997; Mitchel, 2004). It grows well from sea level to 1,200 m where the temperature does not fall below 20^0C. The optimum monthly temperature for a cashewnut tree growth is 27^0C. The cashewnut tree is grown in areas with rainfall ranging from

800 – 1600 mm per annum. The crop is best adapted to the coastal areas (Shomari, 2000, 1990; Orwa et al., 2009).

The area under cashewnut trees cultivation in Tanzania has been estimated to be about 400,000 ha either in mono or mixed crop production systems. It is estimated that over 80% of the crop comes from Mtwara, Lindi and Ruvuma regions (Shomari, 1990; Topper et al., 1998; Ngatunga et al., 2003; Masawe, 2006). This estimate might be underestimated since the area occupied by wooded crops which include cashewnut trees in Mtwara, Lindi and Ruvuma is about 724,000 ha and that of Pwani region are 88,000 ha (MNRT, 2015).

While other uses of cashewnut trees are widely documented, information about carbon (C) storage potential is scanty or not available in Tanzania. Many studies were focused on natural forests and plantations of timber trees (Mugasha et al., 2013; Alvarez et al., 2012; Abbot et al., 1997). Studies on C storage potential of other agroforestry systems have been carried out in Tanzania (e.g. Kimaro et al., 2011), but none has presented C sequestration potential of agro-forestry systems with cashewnut trees.

The aim of this chapter is therefore to describe recently developed biomass and volume models for cashewnut trees in Tanzania.

11.2 Site description

Data for development of biomass and volume models were collected from Kisarawe district (38° 44" 12' E; 7° 15" 44' S), Pwani region. Altitude is about 400 m. The district is located about 78 km from the coastal shore. The district receives a mean annual rainfall of 1090 mm and experiences mean annual temperature of 26.1°C. The soils are sandy and fluvisols.

11.3 Data collection and analysis

Selection of sample trees

A total of 45 trees were purchased from farmers for destructive sampling. These trees were used for biomass modelling while 43 trees among them were used for volume modelling. Each sample tree was measured for dbh and ht before felling. A calliper or a diameter tape (for larger trees) was used to measure dbh, while ht was measured using Suunto hypsometer. The diameter at breast height (dbh) of selected trees ranged from 6.0 to 89.8

cm with an average of 35.8 cm. Total height (ht) ranged from 2.5 to 15.5 m with an average of 8.8 m.

Destructive sampling and biomass determination

The determination of tree biomass considered above- and belowground components. Sample trees were felled at 30 cm aboveground level. Aboveground component consisted of stem, branches and twigs. Stem and branches consist all aboveground components with diameter >5 cm while twigs are those with diameter ≤5 cm. Cashewnut trees branch very near to the ground (often <1.3 m), for this reason, stem and branches components were combined since it was not possible to model stem and branches separately. The belowground component consisted of stump, root crown and roots.

Stems and branches were trimmed and crosscut into billets that were convenient to weigh. Each billet was measured for length and mid diameter for volume model development and fresh weight was measured for biomass model development. All 45 trees selected for destructive sampling were excavated for belowground biomass (BGB) determination. The determination of BGB was based on a root sampling procedure as described by Mugasha et al. (2013) where three main sample roots originating from the root crown and three side sample roots originating from the main root were selected for each tree. Based on these sampled main and side roots, models predicting biomass of main and side roots were developed, and subsequently applied to estimate biomass of unexcavated roots.

For each tree component, at least three wood sub-samples with thickness of about 2 cm were cut (from bark to pith) and measured for fresh weight and taken to the laboratory for dry weight determination. The oven dry weight was used to calculate dry to fresh weight ratio (DF-ratio). The DF-ratio was multiplied by respective tree component fresh weight to get biomass. Scatter plots of AGB and BGB versus dbh of individual trees are shown in Figure 11.1.

Volume of individual billets was calculated using Huber's formula. The billets considered for total tree volume were those of the main stem and branches to 5 cm diameter. During modelling, two observations for tree volume were set aside due to their unrealistic values.

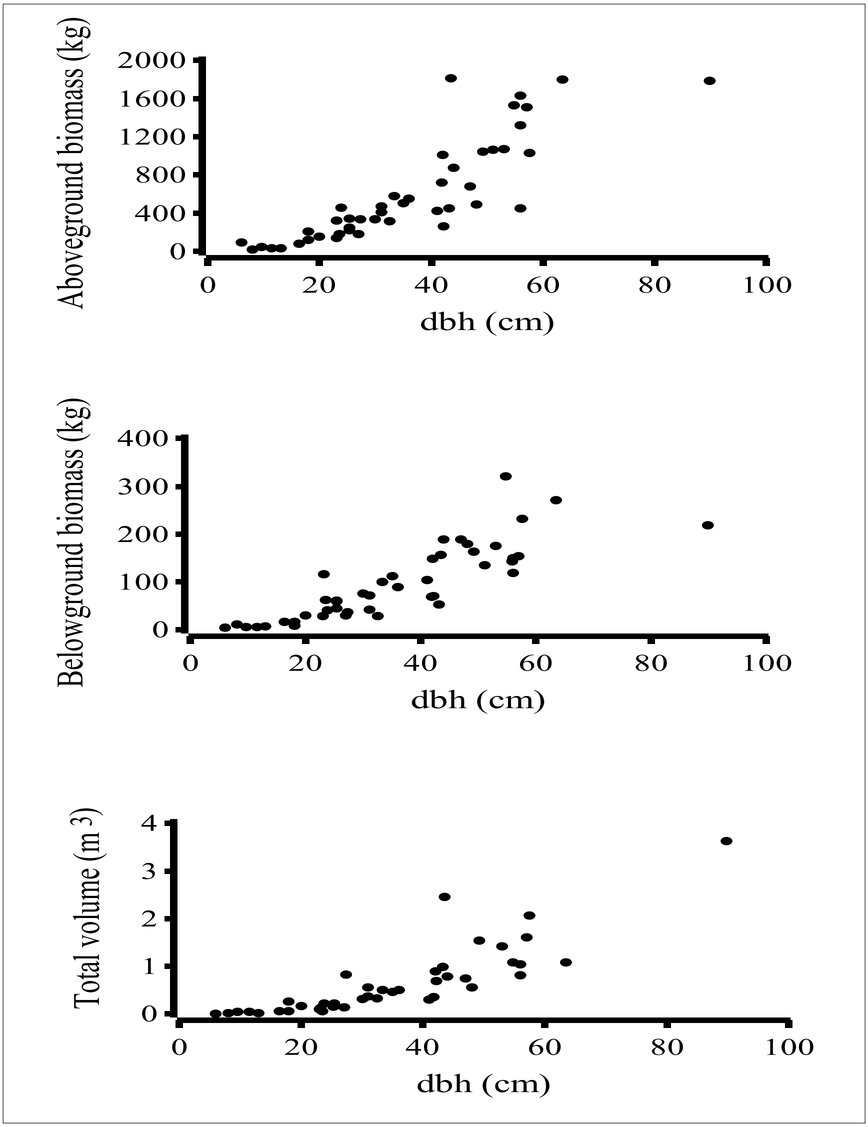

Figure 11.1: Scatter plots of AGB, BGB and total volume versus dbh

Working conditions and resources required

Working conditions in the cashewnut tree stands were conducive. Distance and terrain conditions from the road to the working sites had no impact on time consumption, since most of the farms are accessible by road. Terrain conditions were also favourable.

In contrast to other vegetation types studied where sample trees were provided free of charge by relevant authorities, cashewnut trees for this study were purchased at an average price of TZS 200,000. During the fieldwork, the owners of the trees and neighbours were recruited as members of the crew to facilitate understanding with local communities and avoid conflicts.

It was possible to accomplish two trees of average of 40 cm dbh per day for both above- and belowground component with a crew of 12 people. Table 11.1 summarises the cost estimates used for the cashewnut trees destructive sampling. Note that these estimates excluded the cost of researchers, transport and equipment.

Equipment used during the sampling included diameter tape, calliper, Suunto hypsometer, machetes, axes, chainsaw, hoes, spades, mattock, iron brushes, spring and electronic balances.

Item	**Above- and belowground**
Crew size (persons)	12
Local labour cost per day, per person (TZS)	20,000.00
Average price of the tree (TZS)	200,000.00
Costs per day (TZS)	640,000.00
Trees per day	2
Costs per tree (TZS)	320,000.00

Table 11.1: Cost estimates for destructive sampling

Model fitting and evaluation

Three model forms for biomass and volume were tested. One of the model forms included dbh only and the other two included both dbh and ht:

$$Y = \beta_0 \times dbh^{\beta_1} \quad (1)$$
$$Y = \beta_{0\times} dbh^{\beta_1} \times ht^{\beta_2} \quad (2)$$
$$Y = \beta_0 \times (ht \times dbh^2)^{\beta_1} \quad (3)$$

where Y is biomass (kg) or volume (m^3) and β_0, β_1, and β_2 are model parameters.

Non Linear Programming (NLP) procedure in SAS software (SAS® Institute Inc., 2004) was used to estimate the model parameters (β_0, β_1, and β_2). The procedure produces the least squares estimates of the parameters of a nonlinear model through an iteration process. The procedure fits both model parameters and variance parameters (variance = a^2dbh^{2b}, where a and b are parameters) simultaneously.

The selection of final models was based on the *Akaike Information Criterion* (AIC). AIC takes into account the number of parameters in the models and penalises them accordingly. However, if a model had insignificant parameter estimates, it was not considered further. The coefficient of determination (R^2) and Root Mean Squared Error (RMSE) were reported for all models. In addition, relative mean prediction error was reported as:

$$\mathrm{MPE}\ (\%) = \frac{100}{\mathrm{MB}} \times \sum \left(\frac{e}{n}\right)$$

where e is model residuals (difference between observed and predicted biomass or volume), and MB is mean observed biomass or volume.

11.4 Biomass and volume models

For models predicting AGB and stem-branches components biomass, there are two options: 1) model with dbh only and 2) model with both dbh and ht as independent variables. For model predicting BGB component biomass, there is only one option, i.e. model with dbh only as an independent variable (Table 11.3). The different tree components are defined in Chapter 11.3.

For the models predicting total volume there is only one option, i.e. model with dbh only as anindependent variable (Table 11.4).

11.5 Application recommendations

The presented models for prediction of biomass and volume of cashewnut trees cover relatively narrow ranges of conditions regarding climate, topography and soil; but tree sizes considered were adequate (dbh ranged from 6.0 to 89.8 cm). The models can therefore be applied to most of the cashewnut trees along the coastal zone of Tanzania. It is however recommended that the use of these models beyond this zone need testing.

Component	Model ID	Model	n	RMSE (kg)	R^2	MPE (%)
AGB	CN_S1S1_AGB_1	$B = 0.8450 \times (dbh^2)^{0.8873}$	45	160.6	0.79	-7.6
	CN_S1S1_AGB_2	$B = 0.3152 \times dbh^{1.7722} \times ht^{0.5003}$	45	196.2	0.83	-9.8
BGB	CN_S1S1_BGB_1	$B = 0.09287 \times (dbh^2)^{0.9394}$	45	31.7	0.78	-13.2
Stem-branches	CN_S1S1_SBB_1	$B = 0.0951 \times dbh^{2.2622}$	45	130.9	0.83	-4.0
	CN_S1S1_SBB_1	$B = 0.0659 \times (ht \times dbh^2)^{0.9163}$	45	133.1	0.87	-12.7

Note: B = biomass (kg), dbh = diameter at breast height (cm), ht = total tree height (m)

Table 11.2: Biomass models for cashewnut trees

Component	Model ID	Model	n	RMSE (m^3)	R^2	MPE (%)
Stem-branches	CN_S1S1_SBV_1	$V = 0.0000001 \times dbh^{2.6044}$	43	0.22	0.79	-9.8

Note: V = volume (m^3), dbh = diameter at breast height (cm), ht = total tree height (m)

Table 11.3: Volume models for cashewnut trees

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