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Biomass estimation model for small diameter Auri tree (*Acacia auriculiformis* A. Cunn. ex Benth.)

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Abstract. Auri (*Acacia auriculiformis* A. Cunn. ex Benth.) is one of pioneer tree species developed in forest and land rehabilitation. This species can be used as a short-rotation plantation forest for biomass energy source that produces small diameter stem. The potential use of small diameter auri needs to be supported by accurate biomass estimation. This study aims at developing biomass estimation model for young, small diameter auri tree and comparing the local model to generic model. Measurements were carried out on 92 samples of 2-years old auri tree planted with stand densities of 1850-2500 trees/ha. Data was analysed using 8 local models and compared to 5 generic models. Result of the study shows that the best model for estimating small diameter auri biomass is $B1$ model ($B = 0.016(D_{20})^{2.78}$). The comparison of local and generic models suggested that the local model is better in predicting the auri biomass. This model is valid for small diameter auri species in West Nusa Tenggara Province. This model also seems reliable to apply in similar climatic region, but need a local data validation.

1. Introduction

Auri is one of pioneer tree species potentially developed as a biomass energy plantation forest. This species is suitable for biomass energy source for its high calorific value, ability to harvest in short rotation coppice system [1, 2], tolerant and adaptive to drought and marginal land [3]. Auri also one of legume tree species widely known in preventing soil erosion, nitrogen fixation, improving soil fertility, and providing livestock feed [4, 5].

Biomass energy plantations forest are generally designed with short-rotation harvesting system that produces small-diameter trees [6]. Therefore, the development of auri species in biomass energy plantations needs to be supported by reliable productivity estimation. The productivity of biomass energy plantations is the weight of tree trunks, which are the main contributors to the biomass for energy sources. Thus allometric models for estimating biomass in small diameter auri become an important information for short-rotation plantation forest management.

Studies on allometric models for biomass estimation of certain tree species applied for local site-specific had been reported e.g. *Betula pendula* in post agricultural land of Central Poland [7], mixed tree species in logged-over tropical rainforests of Serawak, Malaysia [8], dry duciduous forests of Malawi [9], degraded landscapes of Northern Ethiopia [10], and lowland forest of Tanzania [11]. Generic models developed by Brown, Gillespie [12], Chave, Andalo [13], Chave, Réjou-Méchain [14] and Ketterings, Coe [15] have been widely used for biomass estimation of various tree species in

tropical forests. Other studies try to evaluate the application of generic model for Teak species [16], or compare local model to generic model [17]. These studies are generally developed from data sets dominated by mature and large-diameter trees.

Allometric development on small-diameter trees is rarely studied since it is considered to have a small biomass contribution in the components of the forest [18]. Several studies on young or small diameter trees biomass estimation have been done [19, 20], but none of similar study is applied on auri species. This study aims to develop a model for estimating the biomass of small diameter auri tree biomass, and to test several generic equations as a comparison. This model is expected to contribute to a better forest management, especially for short rotation auri forest for biomass energy.

2. Material and Methods

2.1. Research site
The auri stand measured in this study was located in an biomass energy stand demonstration plot planted at the end of 2015. The biomass energy stand demonstration plot was in the area of Kanar-Luk Forest Management Resort (FMR), Production Forest Management Unit (PFMU) of Puncak Ngengas-Batulanteh. Administratively, this site was located in Labuan Badas Village, Labuan Badas District, Sumbawa Regency, West Nusa Tenggara, Indonesia. Laboratory analysis to measure the moisture content of tree samples was carried out at the Laboratory of Agroforestry Technology Research and Development Center, Ciamis, West Java. Auri tree sampling and laboratory analysis were carried out in November-December 2017.

2.2. Data collection
Samples of 92 auri trees were randomly selected from 2-year-old auri stands. The sample trees represent the density of 2500 trees / ha, 1850 trees / ha and 1250 trees / ha. The number of test samples is based on [21] that the range of samples from 17 to 95 trees is sufficient to predict tree biomass with a standard deviation of 5%.

Table 1. Summary statistics of auri sample trees.

Statistics	D_{20} (cm)	H (m)	Oven-dry weight (kg/tree)
Mean	6.7	4.4	3.6
Standard deviation	1.6	0.9	2.5
Minimum	3.8	2.5	0.4
Maximum	10.8	7.0	13.3

Each sample tree was measured the stem diameter at height of 20 cm above ground level (D_{20}) in cm, and the tree height (H) in m. Tree biomass measurements were carried out destructively by cutting selected sample trees, by felling at a stem height of 20 cm above the soil surface. The felled trees were then separated between the main stem and branches/twigs and leaves. The main tree trunk is immediately weighed as fresh weight (FW) using portable scales. A total of 9 trees from the sample tree were taken as specimen of 300-500 grams wood which were weighed as a fresh weight of specimen. The specimens were dried and weighed as oven-dry weight of specimens. The moisture content of the test sample is calculated as follows:

$$MC = \frac{FWS - OWS}{OWS} \, x \, 100\% \tag{1}$$

Where MC is moisture content of the specimen (in %), FWS is fresh weight of specimen (in gr), and OWS is oven-dry weight of specimen (in gr). Above ground tree biomass is the oven-dry main stem, derived from the stem fresh weight and average of moisture content ($\overline{MC}$) of the specimens, as follow:

$$B = \frac{FW}{\left(\overline{MC}/100\right)+1} \tag{2}$$

Where B is above ground biomass (in kg/tree), and FW is fresh weight of the tree main stem (in kg). The summary statistics of auri tree samples is performed in Table 1.

2.3. Data analysis
The auri stem biomass estimation model was carried out using non-linear regression equations with estimating variables Diameter at stump height (D_{20}) and total tree height (H). The use of diameter at breast height (Dbh) as a biomass estimator is the most commonly used variable in various species, regions and general equations. However, this Dbh variable in some studies is often replaced by a diameter at a certain height above the ground level, especially in observing small diameter trees [10, 22]. Therefore in this study, we applied the diameter at a stump height about 20 cm above ground level.

Table 2. Biomass function used in the model development.

Models		
$B1 = a(D_{20})^b$	*(3)*	*
$B2 = a(D_{20})^2$	*(4)*	*
$B3 = a(D_{20})^b(H)^c$	*(5)*	*
$B4 = a(D_{20})^2(H)^b$	*(6)*	*
$B5 = a(D_{20})^b(H)^2$	*(7)*	*
$B6 = a(D_{20}H)^2$	*(8)*	*
$B7 = a(D_{20}H)^b$	*(9)*	*
$B8 = a((D_{20})^2H)^b$	*(10)*	*
Generic models:		
$B9 = 0.112(\rho(D_{20})^2H)^{0.916}$	*(11)*	**
$B10 = \rho \, x \, exp(-0{,}667 + 1.784\ln(D_{20}) + 0.207(\ln(D_{20}))^2 - 0.0281(\ln(D_{20}))^3)$	*(12)*	**
$B11 = 0.0673(\rho(D_{20})^2H)^{0.976}$	*(13)*	***
$B12 = 0.066(D_{20})^{2,59}$	*(14)*	****
$B13 = 0.11\rho(D_{20})^{2,62}$	*(15)*	****

Remarks: * Models refer to Mokria [10]; ** Chave's model [13]; *** Chave's pantropical model [14]; **** Ketterings' model [15]; $B1 - B13$ = above ground biomass (kg/tree); D_{20} = Stem diameter at 20 cm above ground level (cm); H = tree height (in m); ρ = wood specific gravity; a, b, c = estimated coefficient

The non-linear regression equations applied in this study follows the 8 equations applied by Mokria, Mekuria [10] (Table 2). These models were chosen because it was quite simple in that there is a power function with the variable D_{20} alone or in combination with the variable H. In addition, Mokria, Mekuria [10] used this formula to estimate mixed-species biomass in the Northwestern Ethiopia which is characterized by a monsoonal unimodal rainfall pattern. This type of bioregion is relatively similar to the eastern region of Indonesia such as West Nusa Tenggara.

To compare with the 8 local models of auri species, we also applied generic models developed by Chave, Andalo [13], Chave, Réjou-Méchain [14] and Ketterings, Coe [15] 1 (model of $B9 - B13$). In

Chave's models ($B9 - B11$), variable of wood specific gravity (ρ) was employed in addition to D_{20} and H. The specific gravity of auri wood used in this study refers to the Global Wood Density Database [23 152].

We used Chave's model on $B9$ and $B10$ since these two model were formulated for dry forest stand, and we expected that these models were suitable to the condition of this study site, compared to other equations in Chave et al 2005. Model $B11$ was a pantropical allometric model to modify previous formulas by ignoring bioregion/agroclimate classification [14]. Meanwhile the model $B12$ and $B13$ were Ketterings' models developed from secondary forest in Sumatera, Indonesia, so these models were also expected to fit with the condition of this study site.

To evaluate the performance of the models, we used several parameters, which are Aggregate Deviation (AD), Average Deviation (MD), Bias, Mean Squared Error of Prediction ($MSEP$) and Error index (Ei), as performed in the equations below:

$$AD = \left(\frac{\sum_{i=1}^{n} \hat{B}_i - \sum_{i=1}^{n} B_i}{\sum_{i=1}^{n} \hat{B}_i} \right) \quad (16)$$

$$MD = \left\{ \frac{\left(\sum_{i=1}^{n} \frac{|\hat{B}_i - B_i|}{\hat{B}_i} \right)}{n} \right\} \text{x} 100\% \quad (17)$$

$$Bias = \frac{\sum_{i=1}^{n} (B_i - \hat{B}_i)}{n} \quad (18)$$

$$MSEP = \frac{\sum_{i=1}^{n} (B_i - \hat{B}_i)^2}{n} \quad (19)$$

$$Ei = \sum_{i=1}^{n} |B_i - \hat{B}_i| \quad (20)$$

Where B is actual biomass (in kg per tree), $\hat{B}$ is predicted biomass, $\bar{B}$ is measured mean biomass and n is total number of trees. The best model is determined based on the smalest value or the value close to 0 of those parameters.

3. Result and Discussion
The coefficient of determination on 8 estimation models of the auri biomass shows a fairly high value ranging from 0.66 to 0.90 (Table 3). This means that 60-90% variation in the value of auri biomass can be explained by the variation of variable D_{20} both alone and together with variable H on the $B1 - B8$ model. This R^2 value is higher than the study by Mokria, Mekuria [10] with the same formula for estimating the biomass of multi-species in Northwestern Ethiopia, which reports a range of 0.47-0.82.

Statistical performances shown in Table 4 indicate that the best equations is the $B1$ model. It can be seen that this equation consistently ranks 1-3 based on the smallest value or close to 0 in the value of *AD, MD, Bias, MSEP* and *Ei*. This results suggest that model $B1$, which is a power function, is quite stable to apply in estimating the above ground biomass. Referring to Picard, Rutishauser [24] and Zianis and Mencuccini [25], power function is the most used model in biomass studies. In this study, the value of estimated coefficient of b on $B1$ model is more than 2, which conform the study of Ketterings, Coe [15]. Ketterings, Coe [15] suggests that the coefficient of b in the power function estimating tree biomass consistently follows $b = 2 + c$, where c is estimated from site-specific diameter and height relationship. However, power function on model $B12$ seems overestimate in estimating the biomass compare to $B1$. Estimated coefficient of b in model $B1$ is 2,78 while in $B12$ is 2,59. If it is assumed that $b = 2 + c$, then the difference of these two models would be in c value where it is related to site-specific diameter and height relationship. The c value in $B1$ model is estimated from young auri tree data seet at dry region of West Nusa Tenggara, while the c value in $B12$ model is derived from more mature secondary forest stand at Jambi with average annual rainfall

reaching 3000 mm. Thus, this study also conformed what [25] reported that the estimated coefficient on power function in biomass study would be diverse with stand age, species, site quality, and stand density.

Table 3. Estimated coefficient and coefficient determination (R^2) of each models

Models	Estimated coefficients			R^2
	a	b	c	
$B1$	0.016	2.780	-	0.90
$B2$	0.080	-	-	0.83
$B3$	0.015	2.744	0.055	0.90
$B4$	0.033	0.553	-	0.87
$B5$	0.007	1.558	-	0.68
$B6$	0.003	-	-	0.66
$B7$	0.025	1.442	-	0.76
$B8$	0.018	0.983	-	0.85

Comparison of local versus generic models shows that all of the local models ($B1 - B8$) consistently perform smaller value for all statistic parameters over the generic models (Table 3). The value of those parameters on generic model even seems far bigger compare to local model, especially in *MSEP* and *Ei* values. It indicates that the local models is better to apply for biomass of small diameter auri estimation. The unreliability of generic model for small diameter auri is allegedly because those models were developed by ignoring small diameter sample trees. Chave's model were developed through above 5 cm tree samples in 27 sites of tropical region and 53 sites from wide ranges of climatic condition [13, 14]. While the Ketterings' model were also derived from mostly 5-20 trunk diameter samples and above 15 years old trees [15].

Table 4. Fit statistics of each model

Models	Fit statistics				
	AD	*MD*	*Bias*	*MSEP*	*Ei*
$B1$	**0.0198 (1)**	0.1765 (3)	**-0.0720 (1)**	0.6017 (2)	49.39 (3)
$B2$	0.0653	0.2222	-0.2488	1.0217	350.45
$B3$	-0.0327	0.1819	0.1127	**0.5977 (1)**	**16.99 (1)**
$B4$	0.0310	0.1747 (2)	-0.1138	0.8080 (3)	30.45 (2)
$B5$	-0.1485	0.3119	0.4605	2.0160	73.91
$B6$	-0.0940	0.3353	0.3060	2.0912	75.94
$B7$	0.0223 (2)	0.2068	-0.0813 (2)	1.4386	52.81
$B8$	0.0252 (3)	**0.1648 (1)**	-0.0921 (3)	0.9466	58.20
$B9$	0.6422	0.6529	-3.2267	54.1430	580.53
$B10$	0.7986	0.8068	-10.9516	252.2549	1.290.22
$B11$	0.5608	0.5658	-3.6742	29.3557	169.73
$B12$	0.6514	0.6527	-5.7806	61.0789	686.62
$B13$	0.6772	0.6771	-7.4696	77.7505	269.03

Remarks: Number in parantheses indicates rank

Predicted value of biomass generated from generic model seems to overestimated over the actual value (Figure 1). As seen in the graph, the local model of $B1$ shows that the increase of actual value is fairly equally followed by the increase of predicted value. Different from the generic models ($B9 -$

$B13$), an increase in the actual value is followed by an increase of prediccted value multiple times, especially in the $B10$ model.

Biomass estimation curve based on D_{20} predictor do not form a regular curve for several models. Only in Model $B1 - B3$, $B10$, $B12$ and $B13$, the curve seems to form regular curve as well as the power function curve, while the others are not (Figure 2). The 5 generic models generate overestimate curve from $B1$ curve. While in the local model, model $B1 - B3$ produce almost contiguous curves, but model $B4 - B8$ appear to have a lower value than $B1 - B3$ for D_{20} above 8 cm. If it is assumed that $B1$ is the best model, it indicates that the local model $B4 - B8$ are still relatively valid or produces curves that almost coincide with $B1$, but tend to underestimate on the D_{20} above 8 cm.
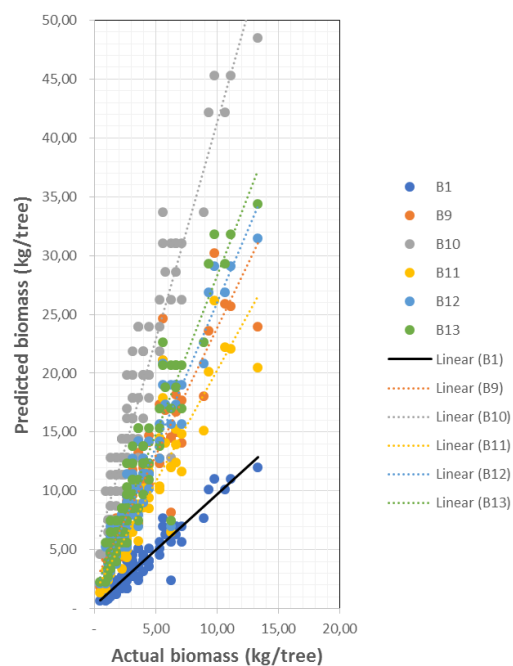

Figure 1. Actual and predicted biomass scatter plot of best local model ($B1$) and generic models ($B9 - B13$)
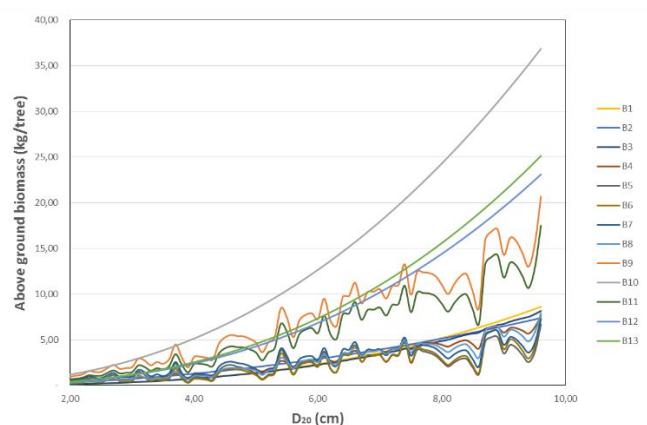

Figure 2. Comparison of above ground biomass estimated based on D_{20} among all models

Result of the analysis suggests that the local models can estimate small diameter auri biomass better than those of the generic. Local model of $B1$ seems the best model as it shows the top 3 ranks for all fit statistic parameters. $B3$ model is also shows a top rank based on $MSEP$ and Ei value, but it requires additional variable of H in the model which requires more cost in measurement process.

4. Conclusion and recommendation
Based on the analysis, the best model for estimating small diameter auri biomass is $B1$ model ($B = 0.016(D_{20})^{2.78}$). The comparison of local and generic models suggest that the local model is better in predicting the auri biomass. This model is valid for small diameter auri species in West Nusa Tenggara Province. This model also seems reliable to apply in similar climatic region, but need a local data validation.

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