International Journal of Research Studies in Biosciences (IJRSB)
Volume 4, Issue 12, December 2016, PP 34-48
ISSN 2349-0357 (Print) & ISSN 2349-0365 (Online)
http://dx.doi.org/10.20431/2349-0365.0412005
www.arcjournals.org

Allometric Equations to Estimate the Biomass of *Oxytenanthera Abyssinica* (A. Rich.) Munro. (Ethiopian Lowland Bamboo) in Dicho Forest, Oromia Region, Western Ethiopia

Fekadu Gurmessa, Teshome Gemechu**, Teshome Soromessa*, Ensermu Kelbessa***

**Department of Biology, Wollega University, Nekemte, Ethiopia
*Addis Ababa University, Addis Ababa, Ethiopia

Abstract: *Ethiopia has over one million hectares of highland and lowland bamboo resources. However, its utilization is fundamentally rudimentary, and its socio-economic and ecological potentials are not yet realized. In addition, bamboo has a great potential for climate change mitigation and adaptation. Hence, the objective of this study was to develop allometric models for estimating above and belowground biomass of lowland bamboo (Oxytenanthera abyssinica (A. Rich.) Munro. in Dicho forest. Thirty four individual bamboo plants were randomly selected from 3 plots of 100m^2 for biomass data collection. Selected plants were extracted out; their basal diameter, DBH and total height were measured using tree caliper and diameter tape after felling the bamboos. The plants were then sorted into four components as rhizome, culm, branch and leaf. Total fresh weight of each part was measured immediately. Subsamples of 15-50 g for leaf and branch, and 100-300 g for stem and rhizome were then taken to the laboratory of Wollega University for dry to fresh weight ratio determination. The subsamples from culm, branch and rhizome were then dried at 105^{o}C and those from the leaf were dried at 70^{o}C in an oven until constant weight was reached. Total dry weight was determined using the dry/fresh weight ratios of subsamples. Basic wood densities of all culm and rhizome discs were determined. The wood volume was determined using the water displacement method. Wood density was then calculated from the ratio of sample dry weight to sample fresh volume. The harvested bamboos were classified into different DBH classes and their biomass share was computed. Linear regression techniques were used to develop allometric models from DBH, height, basal diameter, BA, wood density and their interactions to predict the total above and belowground biomass of bamboo plants. The best models were selected based on residual standard error and the value of coefficient of determination. Results show that the ratio of dry/fresh mass is highest for culms, with and the lowest is for foliage. The mean density of culm is calculated to be 0.49g/cm^3 and that of the rhizome is 0.37g/cm^3. The underground biomass contributed 20.08% of the total biomass. The ratio of belowground to above ground biomass of O.abyssinica is 1:4 (25%). Moreover, the mean dry biomass (in Kg/plant) is calculated to be 2.17, 0.35 and 0.3 Kg for culm, branch and leaf respectively. Regression models indicated that DBH and D10 were found to be the best predictors for TAGB and TBGB respectively.*

Keywords: *Allometric equations, Biomass, Dicho forest, Oxytenanthera abyssinica*

1. Introduction

Bamboo is the common name for member of a particular taxonomic group of a perennial grass with large woody stem or culm belonging to the family Poaceae, subfamily Bambusoideae (Ohrnberger, 1999). It encompasses about 1,200 species within 50 genera (Chapman, 1996; Zhang *et al.,* 2002). Bamboos are giant woody grasses that are widely used resource by human kind. Bamboos occur in the natural vegetation of the tropical and temperate regions of the globe, but are widely distributed in tropical Asia. Africa has rich bamboo species diversity estimated to be about 43 species covering 1.5 million hectares (Kigomo, 1988). Forty of these species are mainly distributed in Madagascar while the remaining three species are found in mainland Africa (Ensermu Kelbessa *et al.,* 2000).

Ethiopia possesses considerable bamboo resources. Two indigenous species of bamboo exist in Ethiopia i.e. the highland or African alpine bamboo (*Arundinaria alpina* K. Schumach.) and a monotypic genus, lowland bamboo (*Oxytenanthera abyssinica* (A. Rich.) Munro. These species are found in some other African countries, but nowhere else outside the African continent (Ensermu Kelbessa *et al.,* 2000). The highland bamboo is distributed in Cameroon, Zaire, Rwanda, Burundi, Sudan and the mountains of Uganda, Kenya, Tanzania and Malawi; while the lowland bamboo is wide-spread, occurring westwards to Senegal and southwards to Zimbabwe (Phillips, 1995). They are indigenous to Ethiopia and endemic to Africa (Ensermu Kelbessa *et al.*, 2000).

Ethiopia has over one million hectares of highland and lowland bamboo resources (Kasahun, 2000). The lowland bamboo is estimated to be about 1,000,000 hectares (Woldemichael Kelecha, 1980), while the highland bamboo is estimated to be 300,000 hectares (LUSO CONSULT, 1997). This implies that 86% of the African bamboo resource is found in Ethiopia. *Oxytenanthera abyssinica* is clump-forming lowland bamboo. The woody culms erect or ascending 3-13 m high and it can attain 5-10 cm in diameter. Culms are nearly solid, silky-pubescent at first. The species grows in savannah woodland, mainly in river valleys and often forming extensive stands (Phillips, 1995). Lowland bamboo in Ethiopia grows only in the western part along major river valleys and in the lowlands bordering Sudan (Ensermu Kelbessa *et al.,* 2000). It occurs between 1100-1800 m.a.s.l. (IBC, 2014). The lowland bamboo has enormous importance for the rural society as there is shortage of proper woody plants for construction in the lowlands.

The economic importance of bamboo is mainly because: (i) it is a superior wood substitute; (ii) it is cheap, efficient, and fast growing; (iii) it has high potential for environmental protection; and (iv) it has wide ecological adaptation; (Carr & Hartl, 2008; Kant, 1996; Kibwage *et al*., 2008; Maoyi & Bay, 2004; Marshall *et al*., 2006; Nugroho & Naoto, 2001; Ogunjinmi *et al*., 2009; Rana *et al*., 2010). Moreover, their strength, straightness, lightness combined with extraordinary hardness, range in size, abundance, and easy propagation make them suitable for a variety of purposes and hundreds of different uses since times immemorial (Rai and Mallik, 2013).

Bamboo culms are used as construction material for housing, fences, and beehives. Moreover, bamboo is also very important for production of household utensils like cups, local pipes, jugs and Jerry cans to carry water. More importantly, a market for bamboo culms and bamboo products has developed in the past years. Many of the landless men engage in producing mats, and furniture e.g. chairs, sofas, and baskets that they sell along the roadside. For these households, bamboo is the major source of income (LUSO CONSULT, 1997). For some people leading traditional way of life, the shoots of bamboo are very important for their nutrition. In addition, bamboo provides most of the fodder for the livestock (LUSO CONSULT, 1997). Bamboo continues to find new uses in various economic sectors including paper and rayon industries, engineering and architecture (Rai and Mallik, 2013). But, it is highly threatened by indiscriminate fire, encroachment by people from the highlands and refugees, overgrazing by livestock and inappropriate agricultural investment practices (IBC, 2009).

Moreover, unlike other countries, the development and utilization of bamboo in Ethiopia is fundamentally rudimentary, and its socio-economic and ecological potentials are not yet realized (Adnew & Statz, 2007). It has received little emphasis and not yet well-integrated into the overall national development planning (Zenebe Mekonnen *et al.,* 2014). Similarly, Ensermu Kelbessa *et al.* (2000) indicated that bamboo was not an integral part of the national economy although it plays a very important role in the socioeconomic activities of the rural communities in the nation.

This amazing tree grass has played and continues to play a significant role in the life and activities of mankind. Hence, assessing the total biomass of bamboo is a useful way of quantifying the amount of resource available for all traditional uses. Biomass studies are also important to judge the performance of this species in terms of total biological production and for issues related to global biogeochemical cycles, especially the carbon cycle and its relation to the greenhouse effect. Attempts to estimate the biomass density of tropical forests have been made by the scientific community in order to assess the contribution of tropical deforestation to the total GHGs in atmospheric air (Brown *et al.*, 1989; Crutzen *et al.,* 1991; Hall and Uhlig, 1991; Houghton *et al.,* 1983). Bamboo has a great potential for climate change mitigation and adaptation (Lobovikov *et al.* 2009; Yiping *et al.* 2010; Nath & Das, 2011; 2012; Wang *et al.* 2011). But, deforestation and forest degradation has led to reduction in bamboo cover especially in the more accessible natural forest areas in Ethiopia (Kassahun, 2000).

For countries, to begin carbon trading, a precise and accurate estimate of the carbon sequestered by forests is very important (Chave *et al.,* 2014). Accurate estimates of carbon stocks depend to a greater degree on the availability and adequacy of the allometric equations that are used to estimate tree biomass (Litton and Kauffmann., 2008; Chaturvedi *et al.,* 2012; Makungwa *et al.,* 2013). Generalized allometry exists for tropical trees (Brown, 1997; Chave *et al.,* 2005), but, allometric model for biomass estimation specific to *Oxytenanthera abyssinica* is scarce. Using generalized allometric models for species such as *Oxytenanthera abyssinica* can cause over or under estimation as the DBH range is usually less than 5cm. Moreover, the difference in climatic zone, species type and the independent variables used for the regression model make the generalized allometric models less suitable to estimate the biomass of *Oxytenanthera abyssinica*. Hence, several authors, including Chave *et al.* (2005); Litton and Kauffmann (2008) and Makungwa *et al.* (2013) and others recommended site and/or species specific allometric models.

Although Girmay Darcha and Emiru Birhane (2015) have developed allometric models for cultivated *Oxytenanthera abyssinica* in Tselemti district of Tigray Regional state, the model was based on only DBH, disregarding height and basal diameter that are important predictors of bamboo biomass. This allometric model also did not account for variability in stand density of natural bamboo forest. In addition, allometric models for predicting belowground biomass were not included. Therefore, new allometric models specific to natural bamboo stands to estimate both above and belowground biomass of low land bamboo are needed. Hence, in this study, we developed new allometric models for predicting above and belowground biomass of Ethiopian low land bamboo (*Oxytenanthera abyssinica* (A. Rich.) Munro. in Dicho forest.

2. Methodology

2.1. Description of the Study Area

2.1.1. Location

This study was conducted on Dicho forest located in Oromia National Regional State, East Wollega zone, Gidda Ayana district. Dicho Forest is located between $9^0 41'00''$ to $9^0 50''00'$N and $36^0 35'03''$ to $36^0 44'00''$E (Figure 1). It is found at a distance of 410 km west of Addis Ababa, along Nekemte-Bure main road. The area has a wide altitudinal variation ranging from 1550 to 2020m above sea level (GPS reading during field data collection). Dicho forest has an area of 12,794.3ha, with 19.8km east–west and 4 to 14.7km North-South dimensions (EWZFWE, 2014).

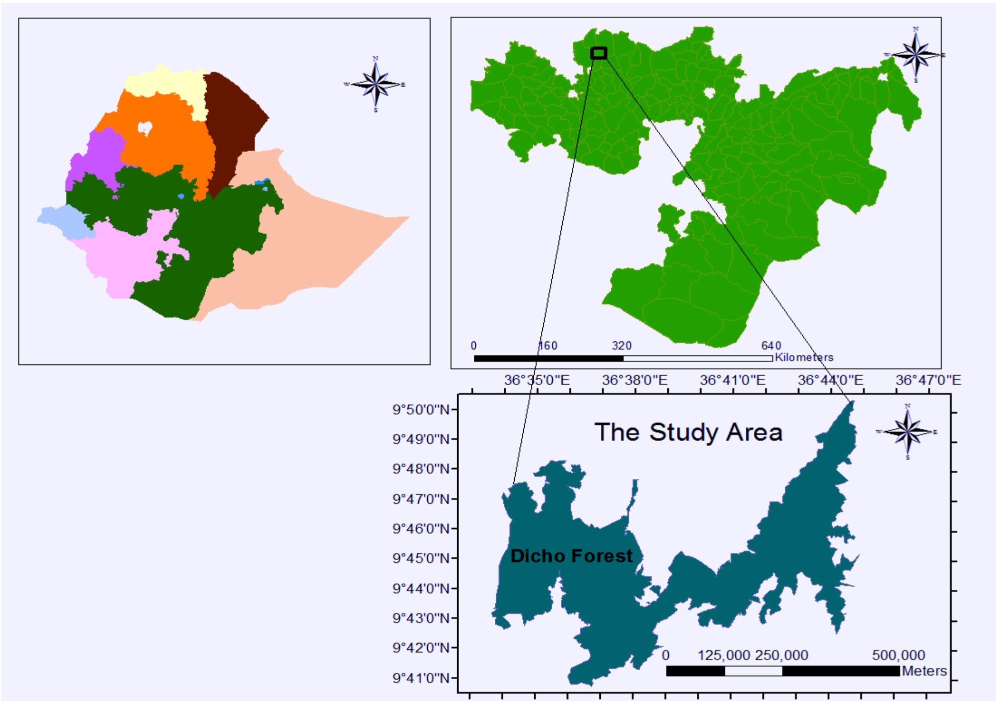


Figure1. *Map of the study area (Dicho Forest)*

The agro-climatic condition of the area is hot lowland to moderately cool and moist temperature at the top edge of Dicho escarpment. The mean annual temperature is about 19°C, and the mean minimum and maximum temperatures are 13.2°C and 26.2°C, respectively. The hottest months are from February to June with maximum temperature record in March and May (2010) (29.58°C) and the coldest months are November to January with minimum temperature of 12.02°C in January (Figure 2). In 2002, however, a minimum temperature of 11.4 °C was registered in the month of March. The mean annual rainfall of the study area is 1,712 mm. The rainfall pattern is unimodal, with little or no rainfall in January and February, gradually increasing to a peak between May and October, and decreasing in November and December (Figure 2).

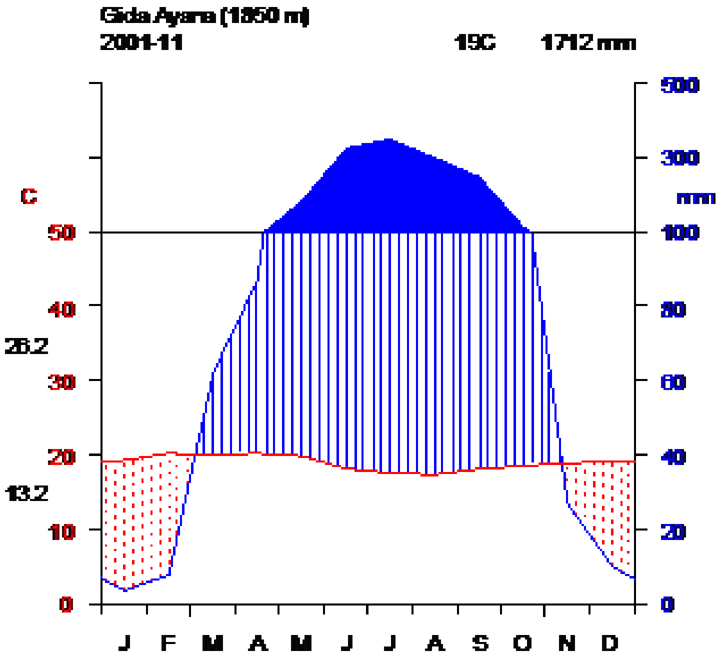


Figure2. *Climate Diagram of Gida Ayana District (2001-2011)*

The vegetation type of the area belongs to the Combretum-Terminalia woodland with the following important tree species. These are *Combretum molle, Combretum adenogonium, Combretum collinium, Terminalia brownie, Terminalia laxiflorium, Protea guagund, Stereospermum kuntbianum* Cham, *Ficus spp. Cussonia spp. Syzygium guneense, Dombeya torrid, Dombey schimperi, Gardenia ternifolia, Gnida glauca* etc. There are also common grass species belonging to the family poaceae These include: *Sporobolus africanus, Cynodon dactylon, Arostis difusa, Hyparhenia cymbaria, Hyparhenia rufa, Hyperrhaenia hirta, Oryza longistaminata, Setaria megapbylla, Snowden polystachya* and *Eriochioa meyeriana. Oxytenanthera abyssinica* is also the dominant plant species occurring in Dicho forest. The most dominant soil type of the study area is Nitosols, (Abdena Deresa, 2015).

Oxytenanthera abyssinica is found to be most relevant for our research because: (1) they accounted for about one million ha of land in Ethiopia (Woldemichael Kelecha, 1980); (2) this woody grass is widely distributed with relatively higher cover abundance across the study area; (3) the species is native to savanna and combretum-Terminalia woodland and has enormous importance for the rural society as there is shortage of proper woody plants for construction in the lowlands (Ensermu Kelbessa *et al.*, 2000).

2.2. Biomass Data Collection

The study area (Dicho forest) was subdivided into three clusters based on altitude, land use history and slope. Suunto Clinometer was used to determine slope of the plots and Garmin 72 GPS was used for recording elevation and geographical coordinates. The land use history of the forest was obtained through visual observation of the area and interview with the local people.

Destructive sampling of bamboo plants was conducted from natural vegetation of Dicho forest in March, 2016. Thirty four individual bamboo plants were randomly selected from 3 plots of 10m × 10m (100m^2) along altitudinal gradient for biomass data collection. Any parts of the sampled bamboo plants were free from any signs of previous damage by herbivores, humans or any other physical factors. Selected plants were extracted out; their basal diameter (10cm above ground), DBH (1.3m above ground) and total height were measured using tree caliper and diameter tape after felling the bamboos. The plants were then sorted into four components as rhizome, aerial stem (culm), branch and leaf. The minimum diameter at breast height of plants that were considered to be at their full grown stage was ≥1.5 cm.

Total fresh weight of each part was measured immediately with suspension and sensitive balance. Sensitive balance was used for leaf samples as weight of leaf were very small to be measured with suspension balance. Subsamples of 15-50 g for leaf and branch, and 100-300 g for stem and rhizome were then taken for dry to fresh weight ratio determination. The variation in wet weight to dry weight ratio with the age of the culm is one of the complicating factors as younger culms are wetter. This has a negative impact for those ratio methods generally used to calculate biomass as it is most unusual to weigh and dry the entire biomass **(**Düking *et al.*, 2011). For this study, subsamples from bamboo culms were taken from the middle of the culm so as to get representative sample along the density gradient of the culm.

All samples then were put into plastic bags and marked with labels. The information labeled on samples include: sample plot code, code of sample tree and sample name. All samples were immediately taken to the laboratory of Wollega University for further analysis. The subsamples from culm, branch and rhizome were then dried at 105°C and those from leaf were dried at 70°C in an oven until constant weight was reached. Total dry weight was determined using the dry/fresh weight ratios of subsamples.

Finally, the fresh and dry-weights of the samples were used to determine coefficient of dry/fresh biomass ratio which was then used to calculate dry biomass of each tree component (culm, branches, foliage and rhizome) of the sample trees from its fresh biomass. Total component dry weight was calculated as follows.

$$\mathbf{TDW} = \frac{SDW}{SFW}\mathbf{TFW}$$

Where; *TDW= total component dry weight; SDW=sample dry weight; SFW= sample fresh weight; and TFW=total component fresh weight.*

Basic wood densities of all culm and rhizome discs were determined at the moisture content of 0%. The wood volume was determined using the water displacement method. Wood density was then calculated with the following formula:

$$\mathbf{SWD}\ (\varrho) = \frac{SDW}{SFV}$$

Where: *SWD (ϱ) =Sample wood density; SDW=Sample dry weight; SFV=Sample fresh volume*

2.3. Data Analysis

All data collected in the field measurement were analyzed using Microsoft Excel for descriptive statistics including, mean, maximum and minimum values; and standard deviation. The harvested bamboos were also classified into different DBH classes and their biomass share was computed. Linear regression techniques were used to develop allometric models from DBH (in cm), height (in m), basal diameter (d_{10}) (in cm), BA (cm^2), wood density and their interactions to predict the total above and belowground biomass of bamboo plants. The ratio of total belowground biomass (TBGB) to total aboveground biomass (TAGB) was also computed. These equations were used in conjunction with the stand data on numbers, diameters, and heights of culms to estimate biomass of each component on a hectare basis. The best models were selected based on residual standard error (RSE) and the value of coefficient of determination (R^2). Moreover, analysis of variance (TukeyHSD ANOVA) was used to compare the mean biomass of the different DBH classes and along altitudinal gradient at ($P<0.05$).

3. Result and Discussion

Thirty four bamboo plants were harvested destructively and all the independent variables were measured. A summary of bamboo parameters are given in the following table (Table 1). The height and DBH of the harvested bamboo plants ranged between 3.83 to 10.8 m, and 1.592 to 4.459 cm respectively (Table 1). The average density of bamboo in Dicho forest is 9000 culms/ha.

Table1. *A summary of Bamboo parameters from Dicho forest (n=34)*

Summary	Height(m)	D10 ()cm	DBH (cm)	BA (cm^2)	Culm density (g/cm^3)	Rhizome density (g/cm^3)
Min.	3.83	2.866	1.592	1.99	0.080	0.110
1st Qua.	6.312	3.862	2.885	6.537	0.402	0.302
Median	7.635	4.665	3.248	8.28	0.495	0.380
Mean	7.363	4.543	3.251	8.598	0.493	0.372
3rd Qua.	7.18	5.287	3.503	9.63	0.590	0.457
Max	10.8	6.051	4.459	15.61	0.820	0.630
sd	1.688	0.930	0.627	3.379	0.178	0.120

3.1. Dry to Fresh Mass Ratio of *Oxytenanthera Abyssinica*

Samples of culm, branch, leaf and Rhizome (including root) were taken from 34 bamboo plants for analysis. The total number of samples for dry mass analysis was 136 consisting of 34 culm, 34 branch, 34 leaf and 34 rhizome samples. The results of dry mass analysis indicated that the ratio of dry/fresh mass is highest for culms, with mean value of 0.64 (value range 0.36–0.88); followed by branches and rhizome with mean value 0.62 (value range 0.35–0.85) and 0.61 (Value range 0.35-0.87) respectively; and the lowest is for foliage, with mean value of 0.58 (value range 0.34–0.81) (Table 2). The mean density of culm is calculated to be $0.49g/cm^3$ and that of the rhizome is slightly lower and it is $0.37g/cm^3$.

Table2. *Dry:Fresh mass ratio of the different components of Oxytenanthera abyssinica collected from Dicho forest*

Summary	Culm	Branch	Leaf	Rhizome
Min.	0.36	0.35	0.34	0.35
Mean	0.64	0.62	0.58	0.61
Max	0.88	0.85	0.81	0.87
sd	0.131	0.133	0.100	0.141

3.2. Bamboo Biomass

Biomass production can vary substantially with individual species even when cultivated on the same site. On average, belowground biomass of sympodial bamboo is about 31% of the total bamboo biomass. Our study, however, indicated that belowground biomass is only 20.08% of the total biomass. Moreover, the portioning of above ground biomass is in the ratio of 77% for culms, 13% for branches and 10% for leaves for sympodial bamboos (Klenihenz and Midmore, 2001). Our study also indicated that the largest proportion of biomass of *Oxytenanthera abyssinica* is contributed by the culm which is 75.95% (value range 73.75-78%). This is followed by branch and leaf with 13.29% (value range 12.99-13.45%) and 10.76% (value range 9.01-12.8%) respectively (Table 3). This is in agreement with Klenihenz and Midmore (2001) for sympodial bamboo. Similar trend was reported by Yigardu Mulatu (2012) in which the largest proportion of biomass is contributed by the culm of highland bamboo (*Arundinaria alpina*). The culm of *O.abyssinica* alone contributed 61.27% of the total bamboo biomass. The branch and leaf contributed 9.83% and 8.57% of the total biomass respectively. Generally, the aboveground components contributed the majority of the biomass which is 79.92%.

Table3. *Mean biomass contributed by the different aboveground components of Oxytenanthera abyssinica in Dicho Forest*

DBH class	Proportion of Biomass (%)		
	Culm	Branch	Leaf
1.5-2.49 cm	73.75	13.45	12.8
2.5-3.49 cm	76.1	13.43	10.47
3.5-4.49 cm	78	12.99	9.01
Mean	**75.95**	**13.29**	**10.76**

The underground biomass, although significantly lower, contributed 20.08% of the total biomass of which nearly 20% is from rhizome. The biomass of the root is small and contributed only less than 0.5% of the total biomass. The ratio of belowground to aboveground biomass of *O.abyssinica* is calculated to be 1:4 (25%). This is in agreement with Shanmughavel and Francis (2001) in which below to aboveground biomass ratio for bamboo plants was between 0.69 and 0.04; although this ratio depends on plant species and age. Moreover, the mean dry biomass (in Kg/plant) is calculated to be 2.17, 0.35 and 0.3 Kg for culm, branch and leaf respectively (Table 4).

Table4. *Summary statistics of dry mass (Kg/plant) of the different components of low land bamboo (Oxytenanthera abyssinica) sample plants (n=34); sd: standard deviation*

	Culm	**Branch**	**Leaf**
Mean	2.17	0.35	0.30
Minimum	0.70	0.003	0.0005
Maximum	4.54	1.26	0.90
sd	0.81	0.25	0.26

There is a wide range of variation on the average bamboo biomass ranging from about 7 t/ha to nearly 200 t/ha (Kleinhenz and Midmore, 2001). LUSO CONSULT (1997) also indicated that the average biomass of the culms of the highland bamboo amounts to be 51.3 t/ha whereas that of the lowland bamboo amounts to be 70.3 t/ha. According to the present study, however, the mean biomass of *O. abyssinica* in Dicho forest is only 25.38 t/ha. This might be due to the dominance of small sized bamboo culms (usually DBH <5cm) in the forest.

The size distribution of bamboo plants in different DBH classes is indicated in table 5. Accordingly, 23.53% belongs to the lowest DBH class while 41.18% and 35.29% are from the intermediate and higher DBH classes respectively. Similarly, the highest and the intermediate DBH classes contributed the majority of the total aboveground and belowground biomass, which is 83.93% and 81.36% respectively. Although the intermediate DBH classes contributed the highest density (41.18%), its share to the total above and belowground biomass is less than those in the higher DBH classes. This indicates that bamboo plants with larger DBH are important biomass and carbon reserves although their density is lower (Table 5 and Figure 3).

Table5. *Frequency and Biomass of bamboo plant in different DBH classes: Where TAGB (Total aboveground biomass), TBGB (Total belowground biomass), and RF (Relative frequency)*

DBH class	**DBH class range**	**Frequency**	**RF (%)**	**TAGB (Kg)**	**%TAGB**	**TBGB (Kg)**	**%TBGB**
1	1.5-2.49 cm	8	23.53	15.45	16.07	4.09	16.94
2	2.5-3.49 cm	14	41.18	38.03	39.56	9.58	39.67
3	3.5-4.49 cm	12	35.29	42.64	**44.37**	10.48	**43.39**
Total		**34**	**100**	**96.12**	**100**	**24.15**	**100**

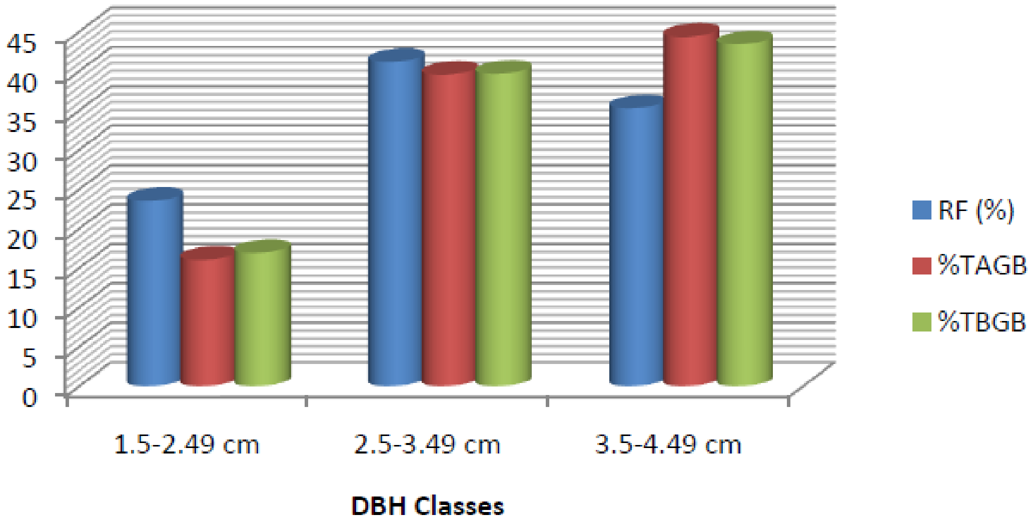


Figure3. *Relative frequency and percentage of total aboveground and belowground biomass of Oxytenanthera abyssinica of different DBH classes in Dicho forest*

Girmay Darcha and Emiru Birhane (2015) have also indicated that larger DBH bamboo plants have accumulated more biomass than small DBH ones. Similar trend was also observed by Shanmughavel and Francis (2001) in which bamboo biomass increase with increasing DBH and height. However, while biomass of culm is increasing with increasing DBH, the proportion of biomass of branch and leaf slightly decreased with increasing DBH (Figure, 4).

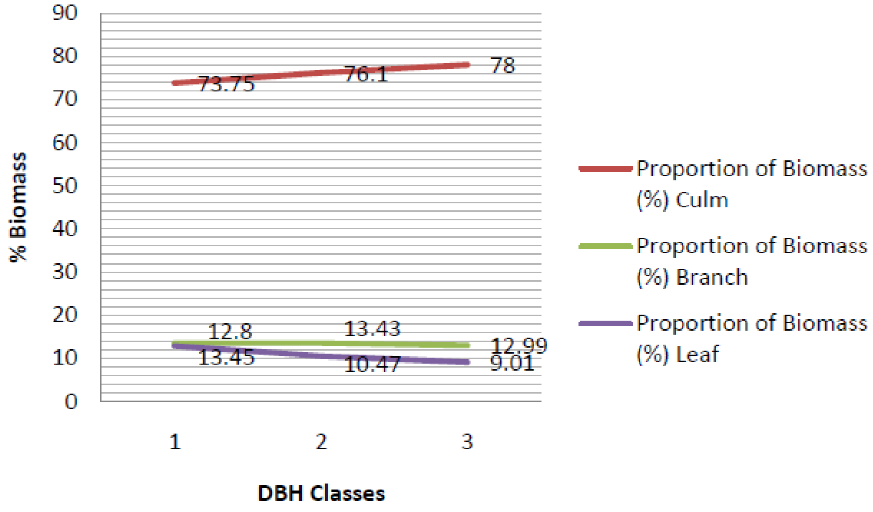


Figure4. *Trends in proportion of aboveground biomass components in different DBH classes (DBH class **1**: 1.5-2.49; **2**: 2.50-3.49; **3**: 3.50-4.49)*

The Relationship between the DBH classes and biomass can also be demonstrated graphically using boxplot. Box plots can be used to make a visual comparison of the differences among groups. Those DBH classes that are significantly different have different heights while those not significantly different have almost the same height. The significant effect of age, which can be inferred from DBH classes, on biomass is depicted by the figures below (Figure 5), which have different length for different DBH classes.

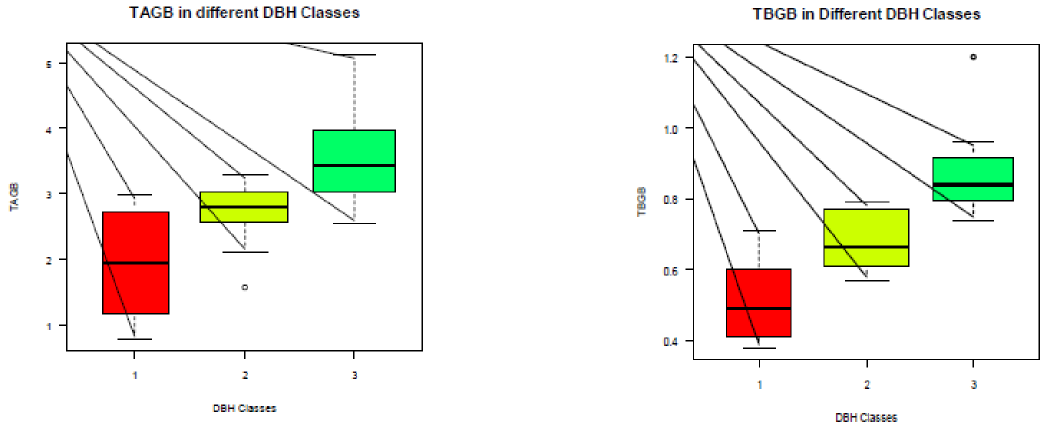


Figure5. *Total aboveground biomass and total belowground biomass of Oxtenanthera abyssinca (Ethiopian low land bamboo) in different DBH classes (DBH class **1**: 1.5-2.49; **2**: 2.50-3.49; **3**: 3.50-4.49)*

ANOVA test was conducted to evaluate mean differences between groups. The variance ratio (*F*-ratio) was then used to test the null hypothesis (H_0) that the population group or treatment means are all equal. Accordingly, Tables 6 indicate that there is a significantly different biomass in different DBH classes (P=0.000 for TAGB and 0.0013 for TBGB). Hence, as bamboo DBH increases so does the amount of biomass. This implies that low land bamboos with higher DBH can accumulate more biomass and carbon in Dicho forest.

Table6. *Analysis of Variance Table*

Response:	TAGB					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
DBHClass	1	12.901	12.9011	28.445	7.532e-06	***
Residuals	32	14.514	0.4535			

Response:	TBGB					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
DBHClass	1	0.10575	0.105745	12.486	0.001271	**
Residuals	32	0.271	0.008469			

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

On the other hand, ANOVA test was conducted to test whether or not there is significant variation in biomass along altitudinal gradient (Table 7). The table indicate that there is no significant variation in biomass along altitudinal gradient (P=0.3229). Hence, although *O.abyssinica* grows in relatively wider altitudinal range, its biomass is not significantly affected by elevation in Dicho forest. Similarly, the significant effect of altitude on bamboo biomass is also depicted by box plot (Figure 6), which shows insignificant variation in length of the box plot along altitudinal gradient.

Table7. *Analysis of Variance table on the effect of altitude on bamboo biomass*

Response:	Total.Biomass				
	Df	Sum. Sq	Mean Sq	F Value	Pr(>F)
Altitude	1	1.114	1.1138	1.0082	0.3229
Residuals	32	35.349	1.1047		

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

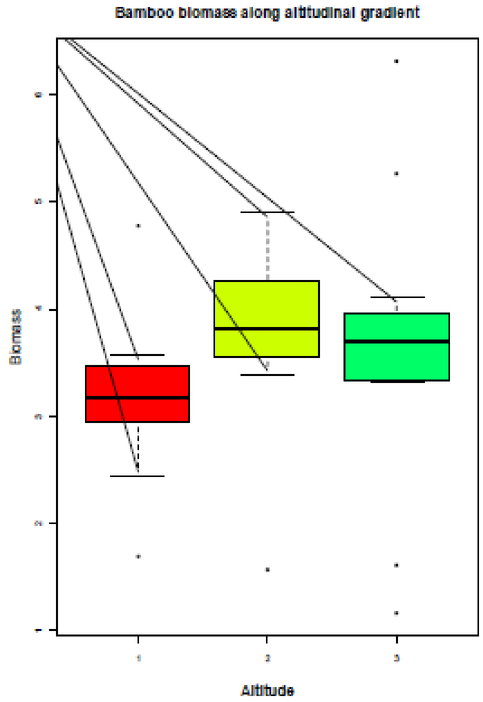


Figure6. *Bamboo Biomass along altitudinal gradient* ***(1: 1550-1650; 2: 1651-1750; 3: >1750 masl)***

3.3. Allometric Equations for Bamboo Plant (Oxytenanthera abyssinica)

Biomass models were developed by regression method using R version 3.1.1 (R Foundation for statistical computing platform, 2014). The purpose of a regression analysis is to develop a model that can be used to predict response variables within or outside the range of the experiment. Although it is possible to predict response values using the regression equation, the uncertainties in both the calculated slope and intercept will likewise render the predicted response value uncertain.

The development of linear allometric equations to estimate TAGB and TBGB of individual bamboo trees in Dicho forest was implemented for the destructively harvested bamboo plants. Accordingly, the linear model in the form of Y = a + b*X (where: Y is biomass, a and b are constant parameters, and X is independent variable such as DBH, Height, Basal diameter and/or basal area or a combination of these variables), was used to develop allometric models for bamboo.

Many possibilities were tried using DBH, height, basal diameter (D_{10}), basal area (BA), wood density (ϱ) and their combinations and logarithmic transformations as predictor variable. Those models with the higher coefficient of determination (R^2) and smaller residual standard error (RSE) are considered to be the best models for TAGB, TBGB, culm dry weight, branch dry weight and leaf dry weight calculations. Generally, 14 allometric models, using one predictor variable, to estimate TAGB and TBGB for all measured bamboo components together with their coefficient of determination (R^2) and residual standard error (RSE) are shown in Table 8. R^2 values ranged from 0.025 to 0.82, and 9 out of 14 of the models had R^2 values greater than 0.50.

Accordingly, the log transformed DBH (lnDBH) was found to be the best predictor variable for the total aboveground biomass (TAGB) with relatively highest coefficient of determinations (*R^2=0.82*) and lower residual squared error (*RSE=0.172*) (Figure 7). Similarly, basal diameter at 10 cm above the ground (D_{10}) and its log transformation (lnD_{10}) was found to be the best predictor variable for the total belowground biomass (TBGB) with higher coefficient of determination (*R^2=0.74*) and low residual standard error (*RSE=0.083 and 0.137* respectively) (Figure 7) from a single predictor variables (Table 8). Height was found to be less predictive to the TBGB with R^2=0.51. In the same way, TAGB, TBGB and other aboveground components for bamboo were correlated with predictor variables (p <0.001) (Table 8). The highest correlation was between log transformed TAGB and DBH (0.90), followed by log transformed TAGB and height (0.88). TBGB and D_{10} and their log transformation also have highest correlation (0.86). On the contrary, DBH is poorly correlated to leaf and branch biomass at P<0.001 (Table 8). Similar table indicated that rhizome density is also found to be less correlated and become less predictive to the total belowground biomass of *O.abyssinica*.

Table8. *Allometric models together with RSE and corresponding R^2 for single predictor variable: (DBH: Diameter at breast height; D_{10}: Basal diameter at 10 cm above ground; BA: Basal area) of 34 individuals of Oxytenanthera abyssinica in Dicho Forest*

Eq. No	Regression Equations	RSE	R^2	Independent Variable	Pearson's Correlation	P value
1	$TAGB = -1.339 + 1.281 \times DBH$	0.435	0.78	DBH	0.88	5.28×10^{-12}
2	$lnTAGB = -0.97 + 1.68 \times lnDBH$	0.172	0.82	DBH	0.90	2.06×10^{-13}
3	$TAGB = -0.614 + 0.467 \times Height$	0.464	0.75	Height	0.87	4.103×10^{-11}
4	$lnTAGB = -1.788 + 1.403 \times lnHeight$	0.191	0.77	Height	0.88	6.37×10^{-12}
5	$TBGB = -0.003 + 0.219 \times DBH$	0.11	0.62	DBH	0.78	3.67×10^{-8}
6	$lnTBGB = -1.52 + 0.99 \times lnDBH$	0.159	0.65	DBH	0.80	9.83×10^{-9}
7	$TBGB = 0.165 + 0.074 \times Height$	0.123	0.51	Height	0.99	2.248×10^{-6}
8	$TBGB = 0.053 + 0.149 \times \mathbf{D10}$	0.083	0.74	D_{10}	0.86	7.05×10^{-11}
9	$lnTBGB = -1.906 + 1.054 \times ln\mathbf{D10}$	0.137	0.74	D_{10}	0.86	7.80×10^{-11}
10	$TBGB = 0.822 + (-0.301 \times Rhizome\ \varrho)$	0.174	0.04	Rhizome ϱ	-0.009	0.242
11	$TAGB = 1.376 + 2.943 \times Culm\ \varrho$	0.756	0.33	Culm ϱ	0.033	0.00036
12	$CulmWt = -0.21 + 0.76 \times DBH$	0.61	0.47	DBH	0.68	8.42×10^{-6}
13	$LeafWt = 0.12 + 0.058 \times DBH$	0.27	0.025	DBH	0.16	0.37
14	$BranchWt = 0.15 + 0.062 \times DBH$	0.25	0.032	DBH	0.18	0.31

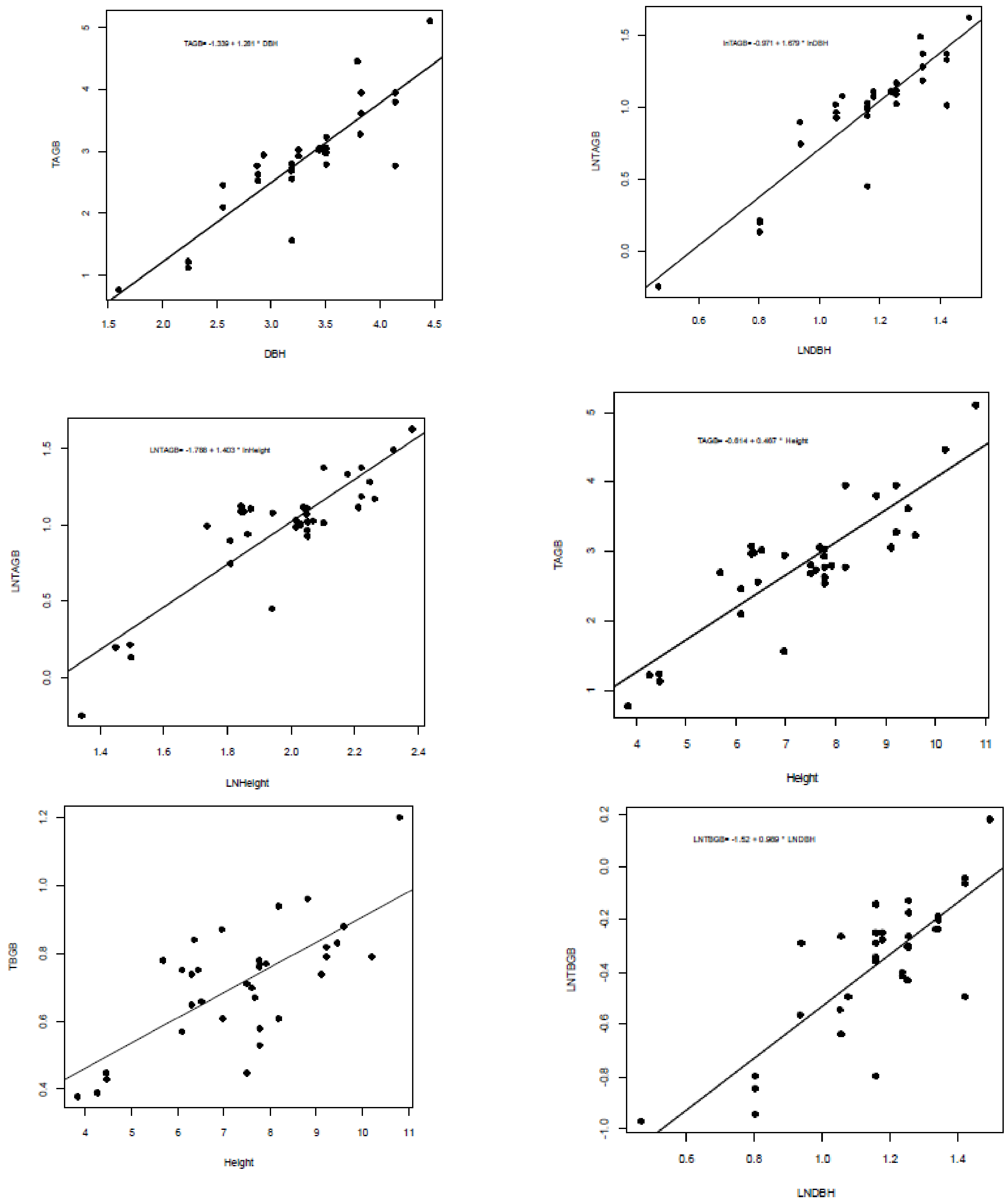
According to Chave *et al.* (2005), the use of tree height, in addition to DBH, as a predictive variable improves the quality of the model. Hence, in order to improve the quality of the regression models for biomass estimation, several allometric models were developed from a combination of all available independent variables, including DBH, Height, basal diameter, wood specific gravity and basal area (Table 9). Thus, 14 out of the 16 regression equations have R^2 value greater than 0.80. Hence, based on the coefficient of determination (R^2) and residual standard error (RSE), we recommend equations number 2 and 15 to calculate TAGB as this equations are with higher coefficient of determination (R^2=0.87 and 0.89 respectively) and lower residual standard error (*RSE=0.151* and *0.318* respectively) (Table 9). In the same way, equation number 8 is found to be the best model to estimate belowground biomass with higher coefficient of determination (*R^2=0.84*) and lower residual standard error (*RSE=0.068*) (Table 9). This implies that DBH, basal diameter (D_{10}) and basal area are important predictors of TBGB.

Table9. *Allometric models together with RSE and corresponding R^2 for multiple predictor variables: (DBH: Diameter at breast height; D_{10}: Basal diameter at 10 cm above ground; BA: Basal area) of 34 individuals of Oxytenanthera abyssinica in Dicho Forest*

Eq.No.	Regression Equations	RSE	R^2	P value
1	$TAGB = -1.073 + 0.067 \times BA + (-0.064 \times D\mathbf{10}) + 0.206 \times Height + 0.653 \times DBH$	0.356	0.866	2.95×10^{-12}
2	$lnTAGB = -1.404 + 0.109 \times lnBA + (-0.147 \times lnD\mathbf{10}) + 0.601 \times lnHeight + 1.032 \times lnDBH$	0.148	0.87	4.86×10^{-13}
3	$TAGB = -1.157 + 0.058 \times BA + 0.203 \times Height + 0.624 \times DBH$	0.351	0.865	3.78×10^{-13}
4	$TAGB = -1.392 + 0.234 \times Height + 0.766 \times DBH$	0.374	0.84	4.07×10^{-13}
5	$lnTAGB = -1.504 + 0.645 \times lnHeight + 1.043 \times lnDBH$	0.148	0.86	1.16×10^{-14}
6	$TBGB = 0.055 + 0.024 \times BA + 0.050 \times D\mathbf{10} + 0.002 \times Height + 0.070 \times DBH$	0.074	0.843	2.95×10^{-11}
7	$lnTBGB = -1.83 + 0.167 \times lnBA + 0.41 \times lnD\mathbf{10} + 0.04 \times lnHeight + 0.39 \times lnDBH$	0.112	0.84	3.6×10^{-11}
8	$TBGB = 0.089 + 0.02 \times BA + 0.06 \times D\mathbf{10} + 0.06 \times DBH$	0.068	0.84	5.29×10^{-12}
9	$lnTBGB = -1.797 + 0.168 \times lnBA + 0.143 \times lnD\mathbf{10} + 0.423 \times lnDBH$	0.11	0.84	1.89×10^{-12}

10	$TBGB = 0.164 + 0.022 \times BA + 0.083 \times D\mathbf{10}$	0.071	0.81	4.89×10^{-12}
11	$lnTBGB = -1.756 + 0.181 \times lnBA + 0.71 \times lnD\mathbf{10}$	0.123	0.79	1.61×10^{-11}
12	$TBGB = 0.165 + 0.029 \times BA + 0.095 \times DBH$	0.072	0.81	6.33×10^{-12}
13	$lnTBGB = -1.575 + 0.257 \times lnBA + 0.601 \times lnDBH$	0.117	0.81	3.01×10^{-12}
14	$lnTBGB = -1.715 + 0.236 \times lnHeight + 0.756 \times lnDBH$	0.156	0.66	2.97×10^{-8}
15	$TAGB = -1.524 + 0.222 \times Height + 0.650 \times DBH + 1.222 \times culm\ \varrho$	0.318	0.89	2.13×10^{-14}
16	$TAGB = -1.483 + 1.128 \times DBH + 1.304 \times culm\ \varrho$	0.384	0.83	9.35×10^{-13}

Although equations for culm biomass with DBH have relatively higher coefficients of determination (R^2=0.47) and lower residual standard error (RSE=0.61), it is not as significant as those of TAGB and TBGB. On the other hand, equations between branch and leaf biomass and DBH have very low coefficients of determination (*R^2=0.025* for leaf; *R^2=0.032* for branch). This indicates that there is a very loose relationship between leaf and branch biomass and DBH of *Oxytenanthera abyssinica* (Table 8 & Figure 7). Hence, it is not recommended to calculate leaf and branch biomass from DBH alone.



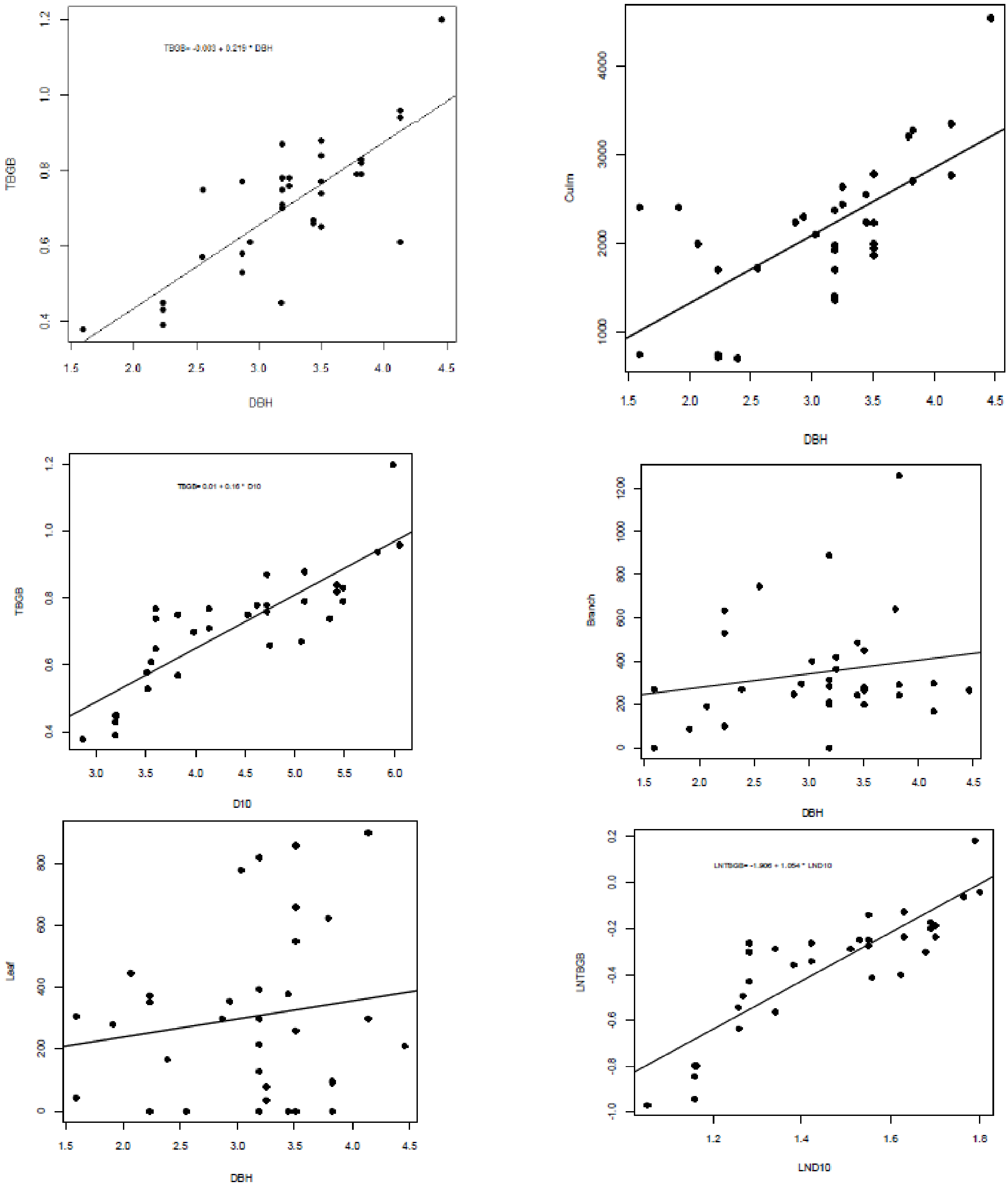


Figure7. *Relationship between TAGB and TBGB of Oxytenanthera abyssinica and predictor variables*

The variation in biomass and carbon stock estimates of forests can be due to the allometric models selected to calculate the biomass and/or carbon stocks. For example, Mehari Alebachew *et al.* (2014) indicated that the generalized allometric models by Brown *et al.* (1989) showed the poorest results with 32-59% average deviation for aboveground biomass predictions of five tree species in Ethiopia. Similarly, the model by Chave *et al.* (2005) was indicated to be unsuitable for three species in Ethiopia including *Allophylus abyssinicus, Olinia rochetiana, and Rhus glutinosa* (Mehari Alebachew *et al.*, 2014). Hence, it is generally agreed that site and species-specific allometric models are ideal to estimate both biomass and carbon stocks of forests.

Site-specific allomeric equations are more accurate in predicting the forest biomass estimates on the local level as it takes the site effects into account (Kim *et al.*, 2011). Accordingly, with regard to the present study, it is indicated that using the generalized allometric equation by Chave *et al.* (2014) cannot make a meaningful comparison as the DBH range is less than 5 cm. Another allometric model developed for a bamboo species (*Melastoma sanguineum* Sims) (DBH range 1.35 - 4.58cm) by Zemek (2009) in Northwest Vietnam was found to make a 10.25% under estimation of TAGB of

Oxytenanthera abyssinica in Dicho Forest. The model developed for plantation of *Oxytenanthera abyssinica* by Girmay Darcha and Emiru Birhane (2015), however, is comparable to the present study with only a 7.77% under estimation of TAGB (Figure 8). Moreover, Yigardu Mulatu (2012) developed allometric models for the different age groups of *Arundinaria alpina* (Highland bamboo). The models for the 2nd and 3rd age classes resulted in relatively similar biomass estimate with the present study (Figure 8).

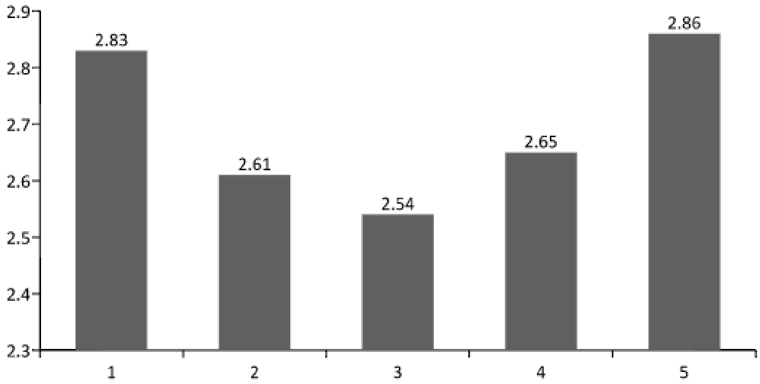


Figure8. *Bamboo biomass using different allometric models*

4. Conclusions And Recommendations

4.1. Conclusions

The carbon content of a forest is the result of many variables. These include the forest type (including geographic location), species or species mix, total area of the stand and stand age (Evans *et al.,* 2008). Moreover, characteristics such as stems per unit area, canopy height, crown width, and leaf cluster index can also determine carbon estimate of a given forest (Evans *et al.,* 2008). Hence, using site-specific allometric models provide more accurate estimate of the biomass stored in plant tissues than models developed somewhere else.

Accordingly, destructive sampling of 34 bamboo plants (*O.abyssinica*) was conducted in Dicho forest. Although biomass of bole, branch and foliage greatly varies depending on species and tree size, there is a general tendency that biomass of bole is the highest, followed by branch and foliage biomass. Biomass distribution in *O.abyssinica* also follows similar trend in which culm accounts the largest biomass, followed by branches and leaf. For lowland bamboo, stem biomass contributed 75.95%; branch and leaf accounts 13.29% and 10.76% respectively. The wood density varies greatly from among species. Wood density was generated for *O.abyssinica*. Hence, the mean wood density of culm is 0.49 g/cm^3, while the mean wood density of rhizome is 0.37 g/cm^3. With regards to regression equation for biomass determination, a total of 30 allometric equations based on variables such as DBH, H, D_{10}, BA and wood density (ϱ), and their combinations were developed for biomass estimation of *O.abyssinica*. Log-transformed DBH (lnDBH) was found to be the best predictor variable for the total aboveground biomass (TAGB) with relatively highest coefficient of determinations ($R^2=0.82$) and lower residual square error (*RSE=0.172*) (Figure 7). Similarly, basal diameter at 10 cm above the ground (D_{10}) and its log transformation ($\ln D_{10}$) was found to be the best predictor variable for the total belowground biomass (TBGB) with higher coefficient of determination ($R^2=0.74$) and low residual standard error (*RSE=0.083 and 0.137* respectively). Generally, the following regression equations are selected and are recommended to be used in the calculation of bamboo biomass from easily measured variables such as DBH, Height and basal diameter (D_{10}) based on the residual standard error and coefficient of determination (Table 10).

Table10. *Selected equations for biomass estimation of Oxytenanthera abyssinica*

No.	Equation	RSE	R^2	P-Value
1	$TAGB = -1.524 + 0.222 \times Height + 0.650 \times DBH + 1.222 \times culm\ \varrho$	0.318	0.89	2.13×10^{-14}
2	$lnTAGB = -1.404 + 0.109 \times lnBA + (-0.147 \times lnD\mathbf{10}) + 0.601 \times lnHeight + 1.032 \times lnDBH$	0.148	0.87	4.86×10^{-13}
3	$lnTAGB = -0.97 + 1.68 \times lnDBH$	0.172	0.82	2.06×10^{-13}
4	$TBGB = 0.089 + 0.02 \times BA + 0.06 \times D\mathbf{10} + 0.06 \times DBH$	0.068	0.84	5.29×10^{-12}
5	$TBGB = 0.053 + 0.149 \times \mathbf{D10}$	0.083	0.74	7.05×10^{-11}
6	$lnTBGB = -1.906 + 1.054 \times ln\mathbf{D10}$	0.137	0.74	7.80×10^{-11}

4.2. Recommendations

- As there is a small DBH range among the bamboos in Dicho forest it is recommended to use data of sample bamboos collected in other regions in the country to cross check the validity of these equations for above and belowground biomass estimation,
- Biomass data from this study should be associated with data of the same vegetation types in different ecological regions within the country to develop general allometric equations that can be applied for above and belowground biomass estimation of bamboo in other regions where equations are not available.
- Finally, the biomass and carbon stored in lowland bamboo could be calculated as per the given allometric equations so that the country will be benefitted from the global carbon trade.

REFERENCES

Abdena Deressa, Bikila Bote, Hirpa Legesse (2013). Evaluation of Soil Cation in Agricultural soils of East Wollega zone in Southwestern Ethiopia. *Sci. Tech. Res. And Arts Journal* **2(1):** 10-17.

Adnew, B., Statz, J. (2007). *Bamboo Market Study in Ethiopia*. Technical report prepared for UNIDO (United Nations Industrial Development Organization). Addis Ababa, Ethiopia.

Brown, S. (1997). *Estimating biomass and biomass change of tropical forests*: a primer. FAO Forestry Paper 134. Rome, Italy.

Carr, M. & M. Hartl. 2008. *Gender and Non-Timber Forest Products: Promoting food security and economic empowerment*. IFAD (International Fund for Agricultural Development), Rome, Italy. www.ifad.org/gender/pub/timber.pdf Accessed 15 April 2011.

Chaturvedi R, Rghubanshi A and Singh J (2012). Biomass Estimation of Dry Tropical Woody Species at Juvenile Stage, *The Scientific World Journal*, 5.

Chave J, Andalo C, Brown S, Cairns M, Chambers, J, Eamus D, Folster H, Fromard F, Higuchi N, Kira T, Lescure J, Nelson B, Ogawa H, Puig H, Riera, B and Yamakura T (2005). Tree Allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145, 87-99.

Chave J, Mechain M and Burquez A *et al*. (2014). Improved allometric models to estimate the above ground biomass of tropical trees. *Global change biology*, 20: 3177-3190.

Dietz J and Kuyah S (2011). Guidelines for establishing regional allometric equations for biomass estimation through destructive sampling (version one). World Agroforestry center, Nairobi, Kenya.

Ensermu Kelbessa, Tamirat. Bekele Alemayehu Gebrehiwot & Gebremedhin Hadera (2000). *A Socio-Economic Case Study of the Bamboo Sector in Ethiopia: An analysis of the production-to-consumption system.* Addis Ababa University, Addis Ababa, Ethiopia. Pp. 34

EWZFWE (2014). East Wollega zone Forest and Wildlife Enterprise annual report. Nekemte, Ethiopia.

IBC (2009). Ethiopia's 4th country Report to the Convention on Biological Diversity (CBD). Addis Ababa, Ethiopia. Pp. 161.

IBC (2014). Ethiopia's Fifth National Report to the Convention on Biological Diversity (CBD). Addis Ababa, Ethiopia. Pp. 72

Kant, S. (1996). Integration of biodiversity conservation in tropical forest and economic development of local communities. *Journal of Sustainable Forestry* 4(1–2):33–61. dx.doi.org/ 10.1300/ J091v04n01_02

Kassahun, E. (2000). The indigenous bamboo forests of Ethiopia: An overview. Ambio, 29(8): 518 521. URL: http:// www.jstor.org/stable/4315085. >: accessed on 5 January 2014.

Kassahun, E., Weih, M., Ledin, S., Christersson, L. (2004). Biomass and nutrient distribution in a highland bamboo forest in southwest Ethiopia: Implications for management. *Forest Ecol. Manage*., 204: 159-169.

Kibwage, J.K., Odondo, A.J., Momanyi, G.M. (2008). Structure and performance of formal retail market for bamboo products in Kenya. *Scientific Research and Essays* 3(6):229–239.

Kigomo, B. N. 1988. Distribution, cultivation and research status of Bamboo in Eastern Africa.

Kim, C., Jeong, J., Kim, R., Son, Y., Lee, K.H. (2011) Allometric equations and biomass expansion factors of Japanese red pine on the local level. *Landscape Ecology Engineering* **7:** 283-289.

Kleinhenz, V. and Midmore, D.J. (2001). Aspects of bamboo agronomy. *Advances in Agronomy* **74:** 99-149.

Litton, M.L., Kauffmann, J.B. (2008). Allometric Models for Predicting Aboveground Biomass in Two Widespread Woody Plants in Hawaii. *Biotropica* **40(3):** 313-320.

Lobovikov, M., Lou, Y., Schoene, D., Widenoja, R. (2009). The Poor Man's Carbon Sink. Bamboo in Climate Change and Poverty Alleviation, Food and Agricultural Organization, Rome, Italy, 72.

LUSO CONSULT. (1997). Study sustainable Bamboo Management: Second Interim Report.

Makungwa, D., Chitock, A., Skolr, L., Phiri, Y., Woodhouse, H. (2013). Allometry for Biomass Estimation in Jatropha Trees Planted as Boundary Hedge in Farmers' Fields. Forests, 4: 218-233.

Maoyi, F., Bay, A.V. (2004). Bamboo: Green and gold in China and Vietnam. Pp. 45–50 in *Riches of the Forest: Food, spices, crafts and resins of Asia*. Edited by C. López & P. Shanley. Center for International Forestry Research (CIFOR), Bogor, West Java, Indonesia.

Marshall, E., Schreckenberg, K., Newton, A.C. (2006). *Commercialization of Non-Timber Forest Products: Factors influencing success. Lessons learned from Mexico and Bolivia and policy implications for decision-makers*. United Nations Environment Programme, World Conservation Monitoring Centre, Cambridge, U.K.

Mehari Alebachew, Ruiz-Peinado, R., Bravo-Oviedo, A., Bravo, F. (2014). Aboveground biomass equations for sustainable production of fuel wood in a native dry tropical afromontane forest of Ethiopia. *Annals of Forest Science*, Springer (submitted).

Nath, A., Das, A. (2012). Carbon pool and sequestration potential of village bamboos in the agroforestry system of northeast India: *Tropical Ecology*, 53(3): 287-293.

Nugroho, N., Naoto, A. (2001). Development of structural composite products made from bamboo II: Fundamental properties of laminated bamboo lumber. *Journal of Wood Science* 47(3):237–242. dx.doi.org/10.1007/BF01171228

Ogunjinmi, A.A., Ijeomah, H.M., Aiyeloja, A.A. (2009). Socio-economic importance of bamboo (*Bambusa vulgaris*) in Borgu local government area of Niger State, Nigeria. *Journal of Sustainable Development in Africa* 10(4):284– 298.

Ohrnberger, D. (1999). *The Bamboos of the World: Annotated nomenclature and literature of the species and the higher and lower taxa*. Elsevier Science, Amsterdam, Netherlands.

Phillips, S. (1995). *Flora of Ethiopia and Eritrea, Poacea (Gramineae)* (Vol. 7). The National Herbarium, Addis Ababa, Ethiopia.

Rai, B. Mallik, B.K. (2013). Biomass accumulation and Nutrient distribution of Meloccana baccifera (Roxb.) Kurth. In Kolasib forest, Mizoram, India. *Indian Journal of Plant Sciences* 2(4): 2319-3824.

Rana, M.P., Mukul, S.A., Sohel, M.S.I., Chowdhury, M.S.H., Akhter, S., Chowdhury, M.Q. Koike, M. (2010). Economics and employment generation of bamboo-based enterprises: A case study from eastern Bangladesh. *Small-Scale Forestry* 9(1):41–51. dx.doi.org/10.1007/s11842-009-9100-8.

Shanmughavel, P. Francis, K. (2001). Bio productivity and nutrient cycling in Bamboo and Acacia plantation forests. *Bioresource Technology* 80:45-48.

Woldemikael Kelecha (1980). The Bamboo Potential of Ethiopia. Forestry and Wildlife Conservation and Development Authority, Addis Ababa, Ethiopia. Monograph. Pp. 14.

Yigardu Mulatu (2012). Growth, Morphology and Biomass of *Arundinaria alpina (Highland Bamboo) (Poaceae)* as Affected by Landrace, Environment and Silvicultural Management in the Choke Mountain, Northwestern Ethiopia. PhD Thesis, Addis Ababa University, Ethiopia.

Yiping, L., Yanxia, L., Buckingham, K., Henley, G., Guomo, Z. (2010). *Bamboo and Climate Change Mitigation: A comparative analysis of carbon sequestration*. International Network for Bamboo and Rattan Technical Report No. 32. Beijing, China.

Zemek, O.J. (2009). Biomass and carbon stocks inventory of perennial vegetation in the Chieng khoi watershed, Northwest Viet nam. M.Sc Thesis. University of Hohenheim. Stuttgart–Germany.

Zenebe Mekonnen, Adefires Worku, Temesgen Yohannes, Mehari Alebachew, Demel Teketay, Habtemariam Kassa (2014). Bamboo Resources in Ethiopia: Their value chain and contribution to livelihoods. *Ethnobotany Research & Applications* **12:**511-524.