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Allometric Equations for Aboveground Biomass Estimation of *Osyris quadripartita* (African Sandalwood) in Semi-arid Woodlands, Southern Ethiopia

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Abstract: African sandalwood, *Osyris quadripartita* Salzm. ex Decne is cosmopolitan in dry evergreen forest, rocky ridges, and forest edges, habitually with *Olea europaea* as well as *Dodonaea angustifolia* woodland in East Africa and Ethiopia. It reaches in Africa from Ethiopia to Algeria and Kenya to South Africa, starting from stunted shrubs to tall trees. Osyris quadripartita is culturally important for herbal medicine and religious activities, and also, commercially for the perfumery oil industry. Recently, the population of the species is endangered in some places, because of overexploitation for commercial values. Even though the species has many economic and ecological functions, its environmental uses like carbon storage and global climate change mitigation are less assessed. Therefore, the study aimed to develop species-specific allometric equations for *Osyris quadripartita* using a destructive method and to evaluate allometric models for estimating the aboveground biomass (AGB) within the semi-arid woodlands forest of Southern Ethiopia. Subsequently, all the needed biomass calculations were done, eight AGB equations were developed. Based on regression equations AGB is related with a diameter at breast height (DBH), height (H), and density (ρ) both individually and in combination. Out of eight, four allometric equations were chosen based on goodness-of-fit statistics, and the others four are rejected. The chosen models were tested for accuracy supported on observed data. The selected models have best fitted with higher R^2-adj and lower residual standard error and Akaike information criterion than rejected equations. The relations for four selected models are significant ($p < 0.001$), which showed a strong correlation of AGB with selected dendrometric variables. Accordingly, the AGB was strongly correlated with three variables combination DBH, Height & Wood density. Individually, AGB was strongly interrelated with DBH, but not significantly interrelated with height and wood density. A specific species equations are better for determining biomass and carbon evaluation than general equations.

Keywords: *Osyris quadripartita*, Species-Specific Equations, AGB, Biomass Valuation, Semi-arid Woodland

1. Introduction

Osyris quadripartita (Africa sandalwood) is a small tree that grows up to 7 m in height. It's an evergreen, root hemiparasitic, and dioeciously plant [1]. The branches of the tree were angular (sharp-edged) and strongly branched. Leaf type is alternate and linear to broadly elliptic shapes and also, blade grayish-green and leathery occasionally rogues on both sides with dense glands. The fruit's color drupe orange to red when ripe, drying pale blackish, having the partial globular form or bottom-heavy, 4.5 to 10 mm in diameter [2]. The flowering period was March-September for females and nearly the entire year for males, with a peak in May-June for both sexes [3].

The plant is indigenous to East African regions and has a wide geographic distribution from Ethiopia to Algeria and Kenya to South Africa, Europe (the Iberian Peninsula and the Balearic Islands), Asia (India-China), and Socotra [4, 5]. The species dispersed in African countries such as Kenya, Tanzania, and also, often found in arid to semiarid areas, mostly on stony and rocky soils [6] and sideways of the margins of dry forests, evergreen bushland, savanna grassland, and abundant at an altitude range of 1275-1800 m above sea level [1]. However, large trees can befall in humid climates, favorably in low soil pH and sufficient soil nitrogen [7]. The plant grows naturally in the areas receiving a mean annual rainfall of 500-700 mm per year. The species is commonly found in the humid highland and semi-arid ecosystem of the southern Ethiopian region [1]. The species were potentially abundant in Gamo Gofa (Mirab Abaya, Arba Minch Zuria, Bonke district), South Omo (Banna Tsemay, Hammer, Malle), and Borena (Yabello & Dire district) [8].

It's culturally and commercially vital species that have been used for herbal medicine, religious activities, and for the perfumery oil industry [9]. In Ethiopia, *Osyris quadripartita* resources have been rummage-sale for cultural purposes [10], nevertheless, the economic contribution to the livelihood of rural societies has not been well-known elsewhere [11]. Since 2012, demands for Osyris quadripartita as raw materials for industrial purposes have increased in Southern Ethiopia [11]. This research was deemed to be crucial before extensive *Osyris quadripartita* populations are exploited and, moreover, to get carbon mitigation potential by developing species-specific allometric equations for *Osyris quadripartita* in dry woodland forests of Southern Ethiopia.

Biomass estimation equations, also recognized as allometric equations which are important to estimate the biomass or volume of aboveground tree components based on diameter at breast height (DBH) and height data from sample trees. Using biomass equations is a mutual and profitable method to estimate the biomass of tree species existing in a forest [12]. A number of condition calls for complete estimates of tree biomass to assessed absorption of carbon in wood, leaves, and roots [13], and as well as an indicator of site productivity, both biological and economic. Allometric equations are significant for measuring biomass and carbon storage inland ecosystems. Numerous biomass-prediction equations have been established from mixtures of tropical species [13, 14]. So far, there is a nonexistence allometric equation for Osyris quadripartita in the study place and similar agro-ecology of Ethiopia.

Until now, the lack of accurate estimates of carbon confiscation in tropical forests is largely part of a scarcity of proper allometric models (focus on generalized models) for predicting biomass in species-rich tropical ecosystems [13]. Still, the use of generalized equations can lead to a bias in estimating biomass for a particular species and site [28], while the latest approaches incorporating data on wood density hold more promise [13]. Accordingly, makers of the equations frequently caution against extrapolation beyond their study area [15]. Therefore, species-specific allometric biomass equations modified to estimate biomass of a specific species in a given biome are essential for providing extra accurate estimates [16]. The study aimed to develop species-specific allometric equations for Osyris quadripartita and evaluate allometric models for estimating the AGB.

2. Materials and Methods

2.1. Description of the Study Area

The study was carried out in Banna-Tsemay district, in the Southern Nations, Nationalities, and Peoples Regional State (SNNPRs), Southern Ethiopia. Geographically, Banna-Tsemay is located between latitude 5° 31' to 5° 34' N and longitude 36° 41' to 36° 46' E. The district elevation ranges from 1100 m to 1800 m above sea level [17]. The rainfall patterns of the study areas are characterized by a bimodal rainfall pattern. The mean annual rainfall is 898 mm while, the mean annual temperature is 25.4°C and the mean annual relative humidity 67.38% was recorded [18]. The dominant vegetation types are *Combretum-Terminalia* woodlands and *Acacia-Commiphora* woodlands and also, the soil type is grouped in the textural class of sandy loam, neutral pH, and exhibited excessive drainage [19]. The livelihoods of the local peoples are based on diverse farming but pastoralist leads over crop production [20].

2.2. Site Selection and Sampling Techniques

The study sites were purposively selected based on the occurrence of relatively intact *Osyris* sites, accessibility, and whether or not Osyris exploitation in the stands for investment was allowed. The selected woodland sites are Mayile (1506 ha) and Shala-Luka (974 ha). Preferential sampling techniques were employed to allow the probability to be involved in all samples needed. A total of 32 *Osyris* plant stems were harvested by destructive methods from different diameter classes. The number of individual *Osyris* trees per diameter class was determined on the root of the relative percentage of *Osyris* trees represented in inventory data.

2.3. Field Measurements

The procedure for field data gathering followed the Manual for Building Tree Volume and Biomass Allometric Equations organized by FAO [21]. A total of 32 *Osyris* plant stems were harvested for AGB estimation and the biometric parameters such as DSH, DBH, and total height (H) were measured before felling each *Osyris* trees (Table 1).

Table 1. *Summary statistics of biometric parameters of the harvested Osyris trees samples (n =32).*

Parameter	Mean	SD	Minimum	Maximum
DBH	9.34	4.93	2.60	22.00
D_{30}	11.07	5.70	3.00	24.50
H	6.51	1.83	3.80	9.30

Where; DBH: diameter at breast height, cm; $D_{30:}$ diameter at stump height, cm; H: average height, m;

After dendrometric measurements of the aboveground biomass (AGB), the sampled Osyris trees were harvested by cutting it at surface level and subdivided into biomass components including foliage, branch, and stem seen in figure 1 [21]. According to [22], the 4-5 cm thickness of discs with 1 m interval was taken on the stem part. For branches, whole the branches from each stem were organized from the thickest to thinnest and from each, the first five cm length was taken to make a combined sample. For the twig plus foliage component, 10 twigs and leaves individually were taken from the branches from each individual stem. The fresh weights of each biomass component were measured in the field on a 150 kg weighing scale to the nearest 0.1 decimal and sub-samples were taken for determination of dry to fresh weight ratio. The collected sample fresh weights were measured in the field by sensitive balance (±0.1 g) and sealed in plastic bags and transported to a laboratory for determination of new volume, moisture, and dry weight measurements. Also, the volume of water displaced is measured using a graduated tube of 100 ml, and the value is used to determine the mean wood specific density ($\bar{\rho}$). In the laboratory, the labeled sub-samples were put in the oven at a temperature of 105°C for wood and 70°C for leaves sample up to net dry mass is obtained for 24 hours [21]. The fresh to oven-dry mass ratios were determined and then, we're used to converting the fresh weights of each biomass component measured in the field into oven-dry weights following [23, 24].

Figure 1. *Photographs of the Osyris plant harvesting.*

(a) multiple stem plant being measured for breast height diameter; (b) tree cutting for biomass (c) biomass component being portioned: stem, branch and foliage and sample discs cross-cutting (d) partitioned of biomass component and disc being taken from stem; (e) discs arrangement for ring determined (f) dry biomass weight at laboratory (Photos: Kedir Erbo, 2018)

2.4. Model Selection and Data Analysis

Raw data were primarily separated for outliers in scatter plots to provide a pictorial assessment of the relationships between the independent variables and biomass components. The biomass equation was evaluated for each biomass component separately (stem, branch, foliage, total aboveground biomass) by means of nonlinear regression power function equations [24, 25] and then, eight (8) different power function equations for allometric relationships were tested in Table 2.

Table 2. *Tested biomass equations for Osyris tree components.*

Model no.	Equation	Source
M1	$Y= b1x (DBH)^{b2}$	Hung *et al.,* 2012; Malimbwi *et al.,* 2016
M2	$Y=b1x (DSH)^{b2}$	Negash *et al.,* 2013
M3	$Y=b1x (DBH)^{b2} x (Ht)^{b3}$	Hung *et al.,* 2012
M4	$Y=b1x (DSH)^{b2} x (Ht)^{b3}$	Birhane *et al.,* 2017b
M5	$Y=b1x (DBH^2)^{b2} x (Ht)^{b3}$	Malimbwi *et al.,* 2016
M6	$Y=b1x (DSH^2)^{b2} x (Ht)^{b3}$	Birhane *et al.,* 2017b
M7	$Y=b1x (DBH)^{b2} x (Ht)^{b3} x (\bar{\rho})^{b4}$	unidentified
M8	$Y=b1x (DSH)^{b2} x (Ht)^{b3} x (\bar{\rho})^{b4}$	Ubuy *et al.,* 2018
C	$AGB = 0.0623 x (\rho D^2H)^{0.976}$	Chave *et al.,* 2014
B	$AGB = 0.623 x DBH^{1.352} x Ht^{0.703}$	Birhanu & Teshome, 2018

Where: Y biomass, DSH (diameter at stump height), DBH (diameter at breast height), Ht (Total height), $\bar{\rho}$ (mean wood density), b_1, b_2, and b_3 are parameters. All possible equations were parameterized for each biomass component (leaves, branches, and stem) and total aboveground biomass. All possible equations were parameterized for each biomass section (leaves, branches, and stem) and total aboveground biomass. Model $AGB=0.0623*(\rho D^2H)^{0.976}$ and Model $AGB=0.623*DBH^{1.352}*Ht^{0.703}$ not parameterized in this study because it was already parameterized.

Allometric equations developed by [24, 25] were adapted for this study to estimate aboveground biomass of woody species like Osyris respectively. The assumption is true because of the equations were developed relatively similar climatic and environmental conditions. The model have also high coefficient of determination and lower AIC value. Moreover, [24] developed allometric equivalences for *Olea europaea* L. subsp. *cuspidata* in Mana Angetu Forest, Ethiopia species-specific and aboveground biomass models for pan-tropical woody species in generally [25]. The present study also was conducted on Banna Tsemay district, Southern part of Ethiopia.

For estimating the aboveground biomass of tropical woody species (kg dry matter/plant), allometric equation developed by Chave *et al.* (2014) was used.

$$AGB_{est} = 0.0673 * (pD^2H)^{0.976}; (\sigma = 0.357; AIC = 3130; df = 4002) \quad (1)$$

Where: AGB is total aboveground tree biomass (kg), *p* is mean woody density (g cm^{-3}), D is diameter at stump height (cm), H is tree height (m)

For estimating the aboveground biomass of *Olea europaea* (kg dry matter/plant) allometric equations developed by Birhanu and Teshome (2018) were used.

$$AGB_{est} = 0.623 * Dbh^{1.352} * Ht^{0.703}; R^2 = 0.947; n = 30 \quad (2)$$

Where: Dbh = diameter at breast height diameter (m), Ht is total tree height (m)

Assessments of best fit for biomass equations were evaluated by means of several goodness-of-fit statistics, specifically the coefficient of determination (R^2- adj), correlation, residual standard error (RSE), mean error, Akaike information criterion (AIC), and p-value [24, 25]. To fit the biomass models, unlike equations (Table 2) with additive fault term were evaluated for each dry biomass weight compartment. The best one was carefully chosen based on the statistics calculated for each equation.

R^2 is the portion of the total dissimilarity in yield that is explained by the model. It is a statistical quantify of how close the data are to the fitted regression line. A value of R^2 = 1 means that all of the variation in the response variable is explained by variation in the explanatory variable, while a value of R^2 = 0 means none of the variation in the response variable is explained by variation in the explanatory variable.

AIC-is a measure of the relative quality of arithmetical models for a given set of data. AIC offers a means for model selection. It's convenient because it explicitly penalizes any extra parameters in the model, by adding 2 (p + 1) to the deviance. When comparing two models, the smaller the AIC, the better the fit is true.

$$AIC = -2\ln(L) + 2p \quad (3)$$

Where; L is the likelihood of the fitted model and p is the total number of parameters in the model.

The best statistical model reduces the value of AIC. As an alternative statistic, we also stated RSE (the standard error of the residuals), as the RSE of the best model is minimized. Various statistics for evaluating goodness-of-fit have also been supported in the literature [26], but AIC and RSE conveyed together to provide sufficient information on the quality of a statistical fit for a mixed-species regression model; similar to AIC, the larger RSE is, the poorer the regression model [13]. A p-value is an approximation of the probability that a specific result or a result more extreme than the result observed could have occurred by chance. In short, the p-value is a measure of the credibility of the null hypothesis [27]. The 'p' value is a number between 0 and 1 and is interpreted in the following way: A small 'p' value (typically ≤0.05) for this study indicates strong evidence of the statistical significance of the work.

Before predicting the models, all regretted logarithm forms model was back-transformed to a power function form. Since the log-transformed data cause bias in biomass estimation [28], the back-transformed results were multiplied by a correction factor [29], CF expressed as:

$$CF = exp\left[\frac{RSE^2}{2}\right] \quad (4)$$

Where: RSE was the residual standard error obtained from model regression. CF is at all times a number greater than 1, and where the larger RSE, is the lesser the regression model, and the higher the correction factor. To display the tendency of the final regression model, we designed the model's relative error against AGB, and we flattened this plot by means of a lowess procedure [30].

2.5. Comparison AGB Equations with Previously Published Equations

The first ranked equations for total aboveground biomass were evaluated its reliability by comparing with the following published and commonly used generic models. To compare the predictive precision of the core general equations established for tropical dry forests [25, 31], the studied site and species-specific fitted models were evaluated using average deviation (S) for estimation values.

$$S\% = 100 * \left[\sum_{i=1}^{n} \frac{\left|\frac{AGB_{predict} - AGB_{measured}}{AGB_{measured}}\right|}{n}\right] \quad (5)$$

The generalized allometric models used to predict total aboveground biomass (kg dry weight) were:

Brown:

$$AGB= exp (-1.996+2.32 * ln (DBH)) \quad (6)$$

and Chave et al.:

$$AGB=0.0673 * (WD * DBH^2 * Ht) 0.976. \quad (7)$$

3. Results

3.1. Dry Biomass of the Species

According to the result from the laboratory analysis, the mean total biomass of harvested sample plants was determined to 12.79 kg/plant (Table 3). The stem, branch, and leaf plus twigs contributed 61.1%, 21.2 and 17.7% of the total Osyris plant dry biomass. The average wood-specific density for the species was 0.675 g $cm^{-3.}$

Table 3. *Mean (±SD), minimum and maximum of dry mass (kg/plant) with biomass components and aboveground biomass for harvested Osyris plants (n=32).*

Biomass components	Dry matter, kg	Minimum	Maximum
Twig +foliage	2.25 ± 1.0	0.42	4.21
Branch	2.71 ± 1.08	0.45	4.41
Stem	7.79 ± 5.50	1.10	23.43
Total AGB biomass	12.79 ± 7.96	3.20	34.77

Table 4. *Spearman correlations between biomass components and biometric parameters of harvested Osyris plant (n = 32).*

Biomass Component	D (cm)	D_{30} (cm)	H (m)	P (g/cm^3)
Twig plus Foliage	0.914**	0.912**	0.765**	0.414*
Branch	0.874**	0.860**	0.810**	0.541**
Stem	0.985**	0.982**	0.863**	0.456**
Aboveground biomass	0.995**	0.992**	0.873**	0.491**

D: diameter at breast height; D10: diameter at 30 cm above ground; H: average height of plant;

Correlation significant at ** P < 0.01, * P < 0.05.

3.2. Biomass Predictor Variables

The Spearman correlations between plant biomass and biometric parameters are shown (Table 4). All the biomass components were significantly ($p < 0.01$) correlated with measured biometric parameters with the least value of mean wood specific density (ρ-) with twig plus foliage. The highest correlation observed between DBH with total aboveground biomass (r=0.995) followed by stem biomass (r=0.985), leaves biomass (r= 0.914) and branches (r= 0.874) biomass. The least significant at ($p < 0.05$) correlation was recorded for mean wood specific density (ρ-) with twig plus foliage (r=0.414) biomass component. The DSH and height were strongly correlated with AGB, followed orderly by stem, branch, and twig plus foliage biomass.

3.3. Biomass Equations for Osyris

The eight (8) parameterized power function comparisons for predicting biomass for each component are existing in (Table 5). For total, stem and branch biomass component model seven (M7) that used the combination of DBH, Height, and Wood density was ranked best overall equation to estimate the aboveground biomass of Osyris plants. The M7 equations explained 99% of the variance in plants both for total aboveground biomass & stem biomass and 74% of the variance in-branch biomass. Also, for leaf biomass Model four (M4) used the DSH combined with Height which could explain 66% of the variance in the leaf biomass component. But, using DSH alone at M2 could also explain data variability by 96%, and DBH alone at M1 could be explained data variability by 98% respectively for the species. While the contribution of height for improving the performance of the equations was not significant for this species. But, wood density input has significant values.

The result showed that for Osyris quadripartita the equations M7 and M3 were ranked best overall for total AGB, stem, and branches, and for leaves biomass respectively. The equation M7 ($R2 = 0.99$, $P<0.000$) that 99% of the variance of the output variable which is aboveground biomass (AGB) is described by the variance of DBH, Height, and Wood density the input variable and the rest of 1% variation of the AGB is explained by other factors. The model statistics were significant, with a p-value of 1.091x10-12 which is very much below $p< 0.001$. The equation M7 explained 99% of the variance in plant stem biomass and total aboveground biomass. Also, equation M3 explained 99% for stem biomass and M8 explained 98% of the variance total aboveground biomass respectively. The model developed for total above-ground biomass in which AIC and Residual standard error were the lowest value using equation M7 (Table 5).

The species-specific equations developed for *Osyris quadripartita* listed order are:

$$AGB_{best} = 0.634 \text{ x } (DBH)^{1.823} \text{ x } (Ht)^{0.154} \text{ x } (\bar{\rho})^{1.484}. \text{ (Model 7, 1}^{st}\text{)}$$

$$AGB_{best} = 0.287 \text{ x } (DBH)^{1.867} \text{ x } (Ht)^{0.215} \text{..... (Model 3, 2}^{nd}\text{)}$$

$$AGB_{best} = 0.346 \text{ x } (DBH)^{1.966} \text{....... (Model 1, 3}^{rd}\text{).}$$

Table 5. *The three top ranked equations and goodness-of-fit performance statistics for estimating biomass (kg dry matter/plant) of Osyris quadripartita species.*

Model no.	Equation	Coefficient				Performance statistics				Rank
		b1	b2	b3	b4	adj. R^2	RSE	AIC	P-value	
Stem (Y)										
M1	$Y= b1x (DBH)^{b2}$	0.306***	1.95***			0.99	0.065	-80.47	<0.0001	3
M7	$Y= b1x (DBH)^{b2} x (Ht)^{b3} x (\bar{\rho})^{b4}$	0.3634***	1.904***	0.054	0.441*	0.99	0.0605	-83.03	<0.0001	1
M8	$Y= b1x (DSH)^{b2} x (Ht)^{b3} x (\bar{\rho})^{b4}$	0.3486***	1.836***	0.117	1.06***	0.99	0.0668	-76.67	<0.0001	2
Branch (Y)										
M1	$Y= b1x (DBH)^{b2}$	0.403***	0.864***			0.74	0.284	14.20	<0.0001	3
M7	$Y= b1x (DBH)^{b2} x (Ht)^{b3} x (\bar{\rho})^{b4}$	0.6548	0.715***	0.185	1.301	0.74	0.281	15.30	<0.0001	1
M8	$Y= b1x (DSH)^{b2} x (Ht)^{b3} x (\bar{\rho})^{b4}$	0.6473	0.697***	0.196	1.531'	0.75	0.279	14.97	<0.0001	2
Leaf (Y)										
M2	$Y= b1x (DSH)^{b2}$	0.363***	0.756***			0.66	0.297	17.14	<0.0001	3
M4	$Y= b1x (DSH)^{b2} x (Ht)^{b3}$	0.308**	0.660**	0.208		0.66	0.301	18.78	<0.0001	1
M8	$Y= b1x (DSH)^{b2} x (Ht)^{b3} x (\bar{\rho})^{b4}$	0.9018	0.632**	1.0825	1.956*	0.70	0.282	15.55	<0.0001	2
AGB (Y)										
M1	$Y= b1x (DBH)^{b2}$	0.346***	1.966***			0.98	0.1394	-31.36	<0.0001	3
M3	$Y= b1x (DBH)^{b2} x (Ht)^{b3}$	0.287***	1.867***	0.215		0.98	0.1381	-31.05	<0.0001	2
M7	$Y= b1x (DBH)^{b2} x (Ht)^{b3} x (\bar{\rho})^{b4}$	0.634'	1.823***	0.154	1.484***	0.99	0.1083	-45.73	<0.0001	1

Note: RSE, AIC, P-value are in kg per plant, n=32, DSH (diameter at stamp height), DBH (diameter at breast height), Ht (Total plant height), $\bar{\rho}$ (mean wood density), Parameters b1, b2, b3, and b4 are the model's fitted parameters, ***p<0.001, **p<0.01,*p<0.05 & ' P<0.1.

Likewise, the overall outcomes show that combination of DBH, Ht, and $\bar{\rho}$ (M7), is the best equation to forecast the branches, stem and total aboveground biomass of *Osyris quadripartita* species (Figure 2).

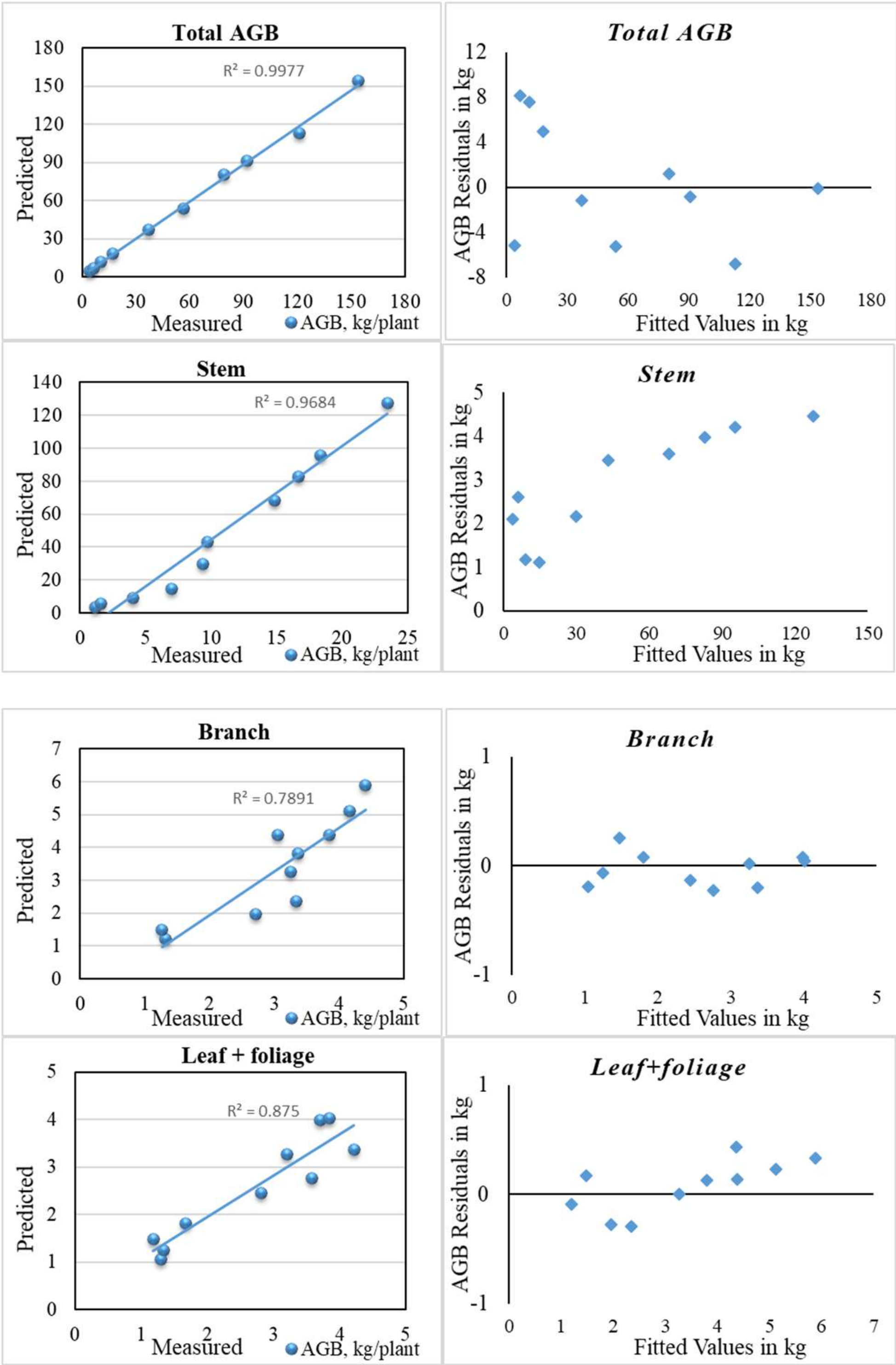

Figure 2. *Plots of total aboveground biomass component models measured versus predicted (left column) and residuals versus Fitted (right column). Equations used for Total AGB, Stem and branch components of Osyris quadripartita, M7 (AGB = 0.634 x $(DBH)^{1.823}$ x $(Ht)^{0.154}$ x $(\bar{\rho})^{1.484}$) and Equations used for Leaves component is M4 (AGB = 0.308 x $(DSH)^{0.660}$ x $(Ht)^{0.208}$).*

3.4. Comparison with Previously Published Biomass Equations

In general, the total aboveground biomass of each sampled tree (kg/plant) predicted using the best performing model equations (M7) made in this study and the most frequently used Tropical dry evergreen general equations developed by [25, 31], are presented in (Figure 3). The result showed that both models on average underestimated for total aboveground biomass per plant from the species were by 15.5% and 27.75% respectively. For this species the average deviation of total AGB biomass resulted from the best-fitted model (M7) value from measured/observed value was 10.4%.

The total aboveground biomass of Osyris quadripartita kg/ha predicted best performing species-specific equations (M7) developed and the two commonly used tropical dry evergreen general equations developed by [25, 31], were 33.34 kg ha-1, 31.77 kg ha-1, & 29.7 kg ha-1 respectively. The developed model is higher total aboveground biomass per hectare than commonly used models.

The overall result showed that the average deviation (S) of the predicted value from the observed value for study species ranges 17-21% by species-specific, [25, 31] models respectively. This indicates that the site-specific species model has fewer average deviation values than general equations.

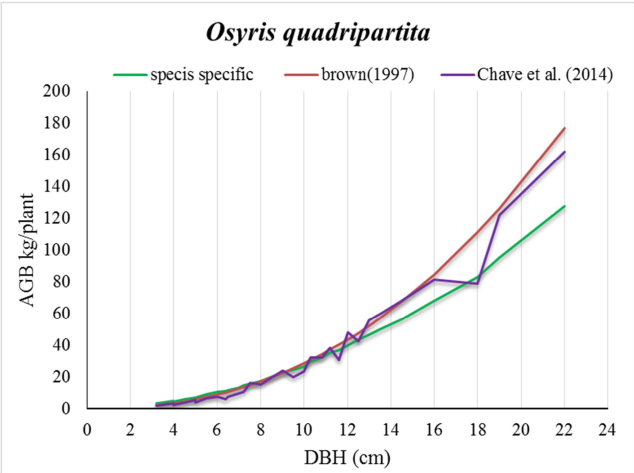

Figure 3. *Allometric equations comparison for the species by total AGB per plant.*

4. Discussion

4.1. Dry Biomass of the Species

In this study, the proportion of the dry mass of the stem wood for *Osyris quadripartita* counted was 61.1%, which dominated the total aboveground biomass. In general, my findings indicated that the stem section accumulated more biomass than the branches and leaves for this species. This result was similar to a previous study conducted by [32] in Chilimo Gajii forest (60-70%) for five dry Afro-montane forest species, and [33] (2014) (46-77%) for three tropical forest species, but it was slightly lower than previous studies found by [34], 70% for 16 tropical rainforest species in Africa.

The branches and leaf biomass was 21.2% and 17.7% respectively, out of total aboveground biomass for the species. The study result was very similar with [32] in Chilimo Gajii forest (30-40%) for five dry Afro-montane forest species specifically with *Olea rochetiana* species. But, it was slightly higher than previous studies found in northeast China forest for branch biomass (3.95-17.27%) and leaf biomass (1.76-11.79%). Leaf biomass was the least proportion of the total aboveground biomass. In this studies probably younger trees DBH <30 cm were considered due to the fact that shortage of financial cost, and time. In general, further studies will be needed to identify driving factors that influence biomass distribution for this species with similar environmental factors.

4.2. Biomass Predictor Variables

Biomass component and aboveground biomass was most strongly correlated to diameter at breast height (Spearman r = 0.87-0.99, p<0.01), diameter at stump height (Spearman r = 0.86-0.99, p<0.01) and total height (Spearman r = 0.76-0.87, p<0.01), (Table 4). According to the finding, results showed that diameter at breast height and diameter at stump height (Spearman r = 0.86-0.99) are better predictors of the total aboveground biomass. These results similar to previous studies showed on DBH by [32, 34, 35], DSH by [23], and total height [36] were the better predictor for aboveground biomass. Likewise, correlations of mean wood density variables with biomass components were least significant as compare to others. This outcome was also, similar to [36] for wood density variables.

For density variable, forest and tree history, topography, soil fertility, the position of the trees in the landscape and the position on the tree where the samples were taken [37] have been reported to influence the wood density of trees of similar and different species and these have to be considered in further studies. Other previous studies indicated that wood density [25, 34, 35] was correlated to aboveground biomass components. Due to this evidence in this study wood density variables were considered for biomass equation development in order to improve the accuracy of the biomass estimate as proven by the previous authors even if it required extra time and cost for fieldwork to obtain reliable data.

4.3. Aboveground Biomass Equations

In this study, we have originated model seven (M7) combined (DBH, Ht & ρ-) revealed that best fitted for predicting the AGB of Osyris species which relatively higher dry biomass (Table 5). Previously available equations for woody species examples of [24, 25] have also stated strong relationships between biometric variables (DBH, Ht & ρ-) and the AGB.

In dissimilarity to this [24] have found that a DBH alone as the predictor variable was also better than models that include height and wood density as supplementary predictor variables. Our study output also showed that DBH/DSH is a strong indicator of AGB which agrees with the earlier reports [38], so DBH alone is a good predictor of biomass, particularly in terms of large regional assessment between accuracy, cost, and practicability of the measurement. Also, the use of the model to determine AGB from DBH only, which had a practical benefit due to most of the inventories include DBH measurements.

The combination of DBH and H has better strength in some equations. A similar result was obtained in the Angetu forest [24]. However, the DBH~H models developed for shrubs and small trees are predicted to have enhanced performance in estimating the AGB of shrubs and small trees within their particular size range variability (DBH <5 cm) [16]. In general, the wood part (stem & branches) and in particular DBH, is an important predictor for Osyris tree species for total biomass but, in woodlands where branching of the stem below breast height is common, diameters of stump height (basal area at ankle height at 5-10 cm above ground level) are often used [39].

Wood density variables are also essential as it varies biomass value among tree genus and species [13]. In general, there was the variability of basic wood density among species, separate of the same species, between topographical location, and through age [40]. Our study showed that wood density was pretentious by tree size. Smaller trees had a low mean value of density, while a high mean density was perceived in large-size trees.

Biomass components and total aboveground equations model seven (M7) were best estimated using a combination of three variables (DBH, Ht & ρ-). The combination of three parameters which explained 99% variation in AGB with logarithm regression model was also able to improve the model goodness-of-fit. However, the second-ranked equation (M3) which using DBH combined with Height could explain the biomass variability by 98%, and hence, can be used to estimate the aboveground biomass of the plant species. The equations presented herein should help investigators to estimate the potential of their resources and to use them efficiently. Based on the range of sample trees examined for this work, the developed equations are suitable for Osyris quadripartita plants with DBH/DSH values ranged between "2.5-30" cm.

This would also help to carry out inventory with limited resources and high accuracy. To the best of our knowledge, there was no previously developed suitable model for predicting the aboveground biomass of the Osyris quadripartita plant, and hence, the equation made in this study would be enabled to accurately estimate the biomass and carbon stock of the species.

4.4. Comparison with Previously Published Biomass Equations

Comparison of generalized models to the best-fitted models for the species in the study site was different accuracy showed that in Figure 3. According to Figure 3, result showed that both authors [25, 31] models have the extremes data range examined when to compare with a species-specific fitted model which means, underestimating total AGB biomass in small trees (DBH 15 cm). The previous studies conducted by [24] in Bale Mena Angetu forest have also reported similarly that, comparison of results obtained from the semi-destructive means of biomass estimation with the generalized equations yield a higher total amount of biomass than the value estimated by the species-specific equation. The gap of biomass amount between the general and species-specific equation was due to the fact that general allometric models are developed for a variety of species without considering climate, density, geographical location, soil type, and other factors relevant to AGB [41].

The overall result has shown that the average deviation (S) of the predicted value from the observed value for study species 21% & 17%, by [25, 31] models respectively. This result was laid between in the range of (14-46%) investigated by [32]. In contrast to this, the species-specific fitted models (M7) evaluated was an average deviation of 11% from the measured biomass values. This indicates that the site-specific species model has fewer average deviation values than general equations, which means the species-specific fitted model was preferable for biomass and carbon estimation assessment than the general equations. Finally, it was generally agreed species-specific allometric models have developed a model to estimate biomass and carbon stocks of forests for similar sites.

5. Conclusion

The allometric equations made in this study enable the precise estimation of the above-ground biomass of the Osyris plant. The aboveground biomass of Osyris plants was found to be strongly correlated with three variables combined (diameter at breast height, Height & Wood density). The power equation using combined (DBH, Ht & ρ-) might describe 99% of the variation in total biomass. The aboveground models (M7) obtained could be used to forecast the biomass and carbon stock of Osyris plants grown in natural ecosystems. Therefore, these studies have made useful allometric equations that allow the prediction of biomass of total aboveground, stem, branches, and leaves for the same genus native woody species. The new models may be applied generally for dry evergreen and semi-arid forest ecosystems, decision-support in forest management, and similar agro-ecology in Ethiopia.

On behalf of worldwide global climate change mitigation, forest justifiable protection, appropriate evaluation, and carbon stock are crucial to the environment. For those concepts, the allometric equation is a crucial tool for estimation AGB. In selecting allometric equations, site- and species-specific equations are very desirable because the general equations are making bias in biomass estimation. In Ethiopia there are many tree species, it's recommended to develop species-specific allometric equations for all of them for better determination of carbon stock to encounter national and international reporting requirements for greenhouse emission inventories.

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