Models for biomass expansion factor of *acacia* hybrid (*A. auriculiformis* A. mangium*) plantations in the Southern region, Vietnam

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ABSTRACT

*Acacia hybrid is one of the favorably fast-growing species which is bring to potential benefits of agro-ecological and socio-economic sectors in Vietnam. The main objective of this study was to develop well-fitted models for estimating biomass expansion factor (BEF) for Acacia hybrid plantations. Fifty-four samples of Acacia hybrid trees from 2 to 10 years of age were collected from Acacia hybrid plantations in the Southern part of Vietnam. Total dry biomass including stems, branches and leaves were used to estimate an average value of BEF. The BEF value was calculated by taking the dry aboveground biomass (W) divided by the volume of merchantable tree woods over their barks (V_m). Twelve allometric equations were fitted by constructing regression models between BEF and inventory variables including diameter at breast height (DBH), height (H) and age (A). Consequently, the average value of BEF was 1.11 ton/m^3. The BEF value had a strongly negative relationship with DBH, height and age in which the BEF value decreased as these three parameters increased. Two best fitted models for estimating a BEF value of Acacia hybrid (A. auriculiformis * A. mangium) plantations included: BEF = 1.99865 - 0.15400*DBH - 0.02123*H + 0.18210*A; and BEF = 3.01307 - 2.44459*ln(DBH) - 0.10171*DBH -2.06212*ln(H) + 1.54556*ln(DBH*H*A). Estimated values of above-ground biomass by utilizing the fitted BEF values from two these models were similar. Results of the study indicated that use of a fitted BEF model is fundamental to obtain reliable estimates of biomass and CO_2 equivalent for Acacia hybrid plantations.*

Từ khóa:
hấp thụ CO_2, hệ số điều chỉnh sinh khối, rừng trồng Keo lai, tỉnh Đồng Nai.

TÓM TẮT

*Keo lai là một trong những loài cây sinh trưởng nhanh, mang lại nhiều lợi ích cho ngành nông lâm nghiệp và kinh tế xã hội ở Việt Nam. Nghiên cứu này nhằm phát triển mô hình phù hợp để ước tính hệ số điều chỉnh sinh khối (BEF) đối với rừng trồng Keo lai. 54 cây từ 2 đến 10 tuổi được thu thập trong các rừng trồng Keo lai ở khu vực miền Nam của Việt Nam. Sinh khối khô thân, cành và lá của cây Keo lai được sử dụng để tính toán giá trị trung bình BEF. Giá trị BEF được xác định bằng sinh khối khô trên mặt đất chia cho thể tích thân cây đứng. 12 phương trình được lựa chọn để xây dựng mô hình tương quan giữa BEF và các biến điều tra gồm đường kính ngang ngực, chiều cao và tuổi cây. Kết quả nghiên cứu chỉ ra rằng, giá trị trung bình BEF là 1,11 tấn/m^3. Giá trị BEF có mối quan hệ chặt chẽ và xu hướng giảm khi đường kính, chiều cao và tuổi cây tăng lên. Hai mô hình phù hợp để ước tính BEF của rừng trồng Keo lai gồm: BEF = 1,99865 - 0,15400*DBH - 0,02123*H + 0,18210*A; và BEF = 3,01307 - 2,44459*ln(DBH) - 0,10171*DBH - 2,06212*ln(H) + 1,54556*ln(DBH*H*A). Sử dụng hai mô hình phù hợp của BEF trong ước tính sinh khối đối với rừng trồng Keo lai cho kết quả tương tự nhau. Kết quả nghiên cứu chỉ ra rằng việc sử dụng mô hình phù hợp của BEF để ước tính của sinh khối trên mặt đất và hấp thụ CO_2 có kết quả đáng tin cậy về sinh khối và hấp thụ CO_2 đối với rừng trồng Keo lai.*

1. INTRODUCTION

Nowadays, forests play important role in the global carbon cycle and the balance of CO_2 concentration in the Earth [1]. Studies on forest biomass and carbon sequestration are significant for planning a management of forest resources and a ultilization of biomass energy resources [2, 3]. Changes in forest biomass are ussualy associated with a growth of forest ecosystems and a rate of carbon absorptions and emissions through their photosynthesis and respiration processess [4]. Chave *et al.* (2005) [5] indicated that an accurate estimation of forest biomass is important in assessing the global carbon cycle. Bouman *et al.* [6] expressed that several studies are interested in determining mechanisms of worldwide carbon sequestration in different environments. It is necessary to develop appropriate methods for surveying and evaluating biomass and carbon stocks of forests [2, 7].

Biomass and carbon storage could be estimated from different approaches that are based on forest inventory data and allometric equations [3], or be calculated indirectly by biomass factors that convert a volume of timbers to dry weight and total aboveground biomass [8, 9]. Using the method of the biomass expansion factor (BEF) to estimate biomass and carbon stocks of forests is widely recommended at the national and regional levels [2, 10] because a BEF has to be directly based on measurements in fields which is defined as a ratio between total stand biomass and growing stock volume [11]. A value of biomass expansion factor can be a constant or varies with an age and stand conditions of trees [9].

Acacia spp. was fast-growing species that have been growed widely in the world's tropical forest. Many studies estimates for biomass of Acacia plantations have been undertaken in Brazil [12], China [13], Indonesia [14], Maylaysia [15],... However, most of the researchers reported about equation and mass biomass of *Acacia mangium* plantations. A study by Miyakuni et al. (2004)[16] in Indonesia showed that the value of BEF didn't differ among the 3-to 8 year-old stands (average 1.3) and decreased to 1.2 in the 10-year-old stand. Similar, the BEF values of *A. mangium* in Côte d'Ivoire decreased with stand age and was 1.66 in 3-year stand, 1.37 in 7-year stand and 1.21 in 11-year stand [17]. The BEF values of Acacia plantations were smaller than the default values reported by IPCC (2003) [18] (mean, 3.4; range, 2.0-9.0) for the tropical broad-leaf forest [16, 17]. In Vietnam, most of recent studies often used the BEFs for the nature forests [19, 20] or/and for the plantations located in the Nothern part of Vietnam [21]. These studies mainly focused on analyzing the biomass expansion factor of *Acacia* hybrid plantations and *Pinus* plantations in the Northern region; however, within our understanding so far, there isn't any studies applied the biomass expansion factor for estimating biomass and C sctock of *Acacia* hybrid planations in the Southern region of Vietnam. Additionally, a change of the BEF is known as depending on the types, growth phases, and site indice of afforestations [22].

Therefore, an estimatation of a BEF with specific condition and area should be preferred and considered [23]. Main objectives of this research aimed to (i) define an average value of BEF, (ii) analyze a correlation between BEF with parameters of tree stand characteristics as diameter at breast height (DBH), height (H) and age (A), and (iii) develop models that are the best fitted to estimate a BEF for *Acacia* hybrid plantations in the Southern region of Vietnam. The result of this study provides a neccesarily scientific basis for management of *Acacia* hybrid plantations and a calculation of payment for forest environmental services in tropical regions generally and in the Southern part of Vietnam particularly.

2. RESEARCH METHODOLOGY

Study site

This research was conducted on *Acacia* hybrid plantations from two to ten years old in different locations of Xuan Loc district, Dong Nai province in Vietnam. Geographic coordinates of the study site were between 107° 26' 52"- 107° 33' 30" in the eastern longitudes and 10° 52' 04"- 11° 01' 18" in the northern latitudes. A slope of the study site is from 3 to 8 degree. The rainy season usually occurs from May to October, while the dry season lasts from November to April in next year. The annual average temperature, rainfall, and humidity are 24.5 °C, 1500 mm, and 76%, respectively. The dominant planted forests in this study include plantations of Acacia hybrid (*Acacia* *auriculiformis* A. Cunn. ex Benth. × *A. mangium* Willd.), *Hopea odorata* Roxb, *Tectona grandis* L.F. and *Pterocarpus macrocarpus* Kurz. These planted forests mainly accounted for 99.8% total the forests area, in which the Acacia hybrid plantations counted 49% of all plantations in the area.

Sample collection

Based on a preliminary survey of the age distribution of Acacia hybrid plantations, standard sampling plots were established to measure criteria for growth of each age group. Twenty - seven standard plots were established for sampling with a plot size of 1000 m^2 (40 m × 25 m) to determine density and above-ground biomass of *Acacia* hybrid plantations from 2 to 10 years old. Fifty-four standard trees were chosen for sample collection by basing on the avarage DBH and logged from each sampling plot for biomass determinantion by using the segmenting method [24-26]. Components of the standard trees which included stems, branches and leaves were collected for measurements of fresh above-ground biomass in situ. In order to determine a dry above-ground biomass, samples of branches, leaves and stems in each sample tree were dried in the laboratory at temperatures 70^0C and 105^0C until their weights were constant. Dried weights of these samples were calculated by the conversion ratio from fresh biomass to dry biomass.

Estimations of biomass and carbon stocks

This study used three different approaches to compare results of biomass and carbon stock estimations. The first method used an equation to estimate BEF by Zhang et al. (2012) [13] for *Acacia* plantations. The second method took the biomass that was calculated from the sample trees. The last method selected the best fitted BEF model to estimate biomass and carbon stocks. The biomass of *Acacia* hybrid plantation was calculated by multiplying the density by the average biomass of the age. Above-ground carbon stocks (tons/ha) was calculated as following equation:

$C = W*P_c$; and aboveground CO_2 equivalent (tons/ha) was equal to C*3,67.

where,

C is plant carbon stocks (Ton. C ha-1);

W is the plant dry biomass (Ton. ha-1);

and P_c is the plant biomass C concentration (%) with P_c = 0.5 [13, 27].

BEF estimation and statistical analysis

IPCC (2003)[18] presented a method to estimate carbon stocks of biomass by using a default BEF value in which that a biomass expansion factor converts from biomass of merchantable sterns to aboveground biomass of trees. Calculation of BEF in this study was shown by the following formula [9, 23].

$$BEF = \frac{W}{Vm}$$

where,

BEF is biomass expansion factor;

W (Ton) is the dry aboveground biomass (including: foliage, branches, stem over bark); and V_m (m^3) is the volume of merchantable tree woods over their barks.

The relationships between BEF and inventory variables including DBH, H and age were fitted by utilizing twelve allometric equations shown in Table 1. These models for a BEF estimation were applied from results of Sanquetta et al. (2011) [28]. Consequently, the best fitted equation of BEF model was selected by based on various goodness-of-fit statistics with the following parameters: the highest coefficient of adjusted determination (R^2 adj), the smallest Akaike information criterion (AIC), the smallest value of root mean squared error (RMSE), and the smallest standard error of estimation (SEE). Statistical analysis of data and regression analysis for developing allometric equations were conducted using Stagraphics centurion XV software package and Microsoft Excel 2016.

Table 1. Equations to estimate models of biomass expansion factor (BEF)

No.	Equations for BEF models	No.	Equations for BEF models
1	m_1*DBH^{-m2}	7	$m_1*\exp(-m_2*DBH)$
2	m_1*H^{-m2}	8	$m1*\exp(-m_2*H)$
3	$m_1*A^{\wedge -m2}$	9	$m_1*\exp(-m_2*A)$
4	$m_1 + m_2*\ln(DBH)$	10	$m_1 + m_2*DBH + m_3*H + m_4*A$
5	$m_1 + m_2*\ln(H)$	11	$m_1 + m_2*\ln(DBH*H*A)$
6	$m_1 + m_2*\ln(A)$	12	$m_1 + m_2*Ln(DBH) + m_3*DBH + m_4*Ln(H) + m_5*Ln(DBH*H*A)$

3. RESULTS

3.1. Mean values of DBH, Height, Age, and BEF of *Acacia* hybrid plantations

As described in Table 2, the estimated average value of BEF for *Acacia* hybrid plantations was 1.11 ton/m^3, ranging from 0.76 to 1.76 with its coefficient of variation of 27.51%. The diameter at breast height (DBH) fluctuated from 3.8 to 16.1 cm with an average DBH of 11.0 cm. The average value of tree height was 13.75 m, increase from 4 m (2 years of age) to 20 m (10 years of age).

Table 2. Mean values of DBH, Height, Age, and BEF of *Acacia* hybrid plantations (n = 54)

Parameter	DBH (cm)	Height (m)	Age (years)	BEF
Mean	11.00 ± 4.15	13.75 ± 4.85	6.00 ± 2.61	1.11 ± 0.30
Minimum	3.80	4.00	2.00	0.76
Maximum	16.10	20.00	10.00	1.76
CV (%)	37.78	35.28	43.44	27.51

Note: Data is presented by Mean ± Standard deviation (SD); DBH: diameter at breast height; BEF: biomass expansion factor; CV: Coefficient of Variation.

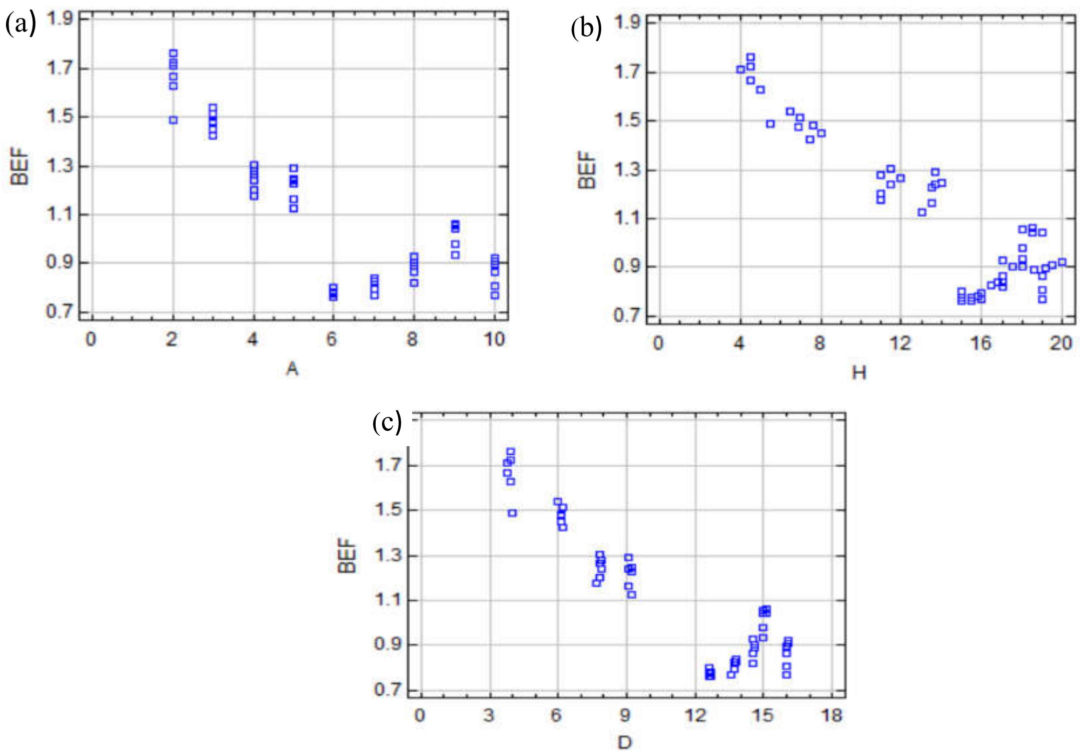


Figure 1. Relationships among total BEF with: a) tree age (A); b) tree height (H); c) DBH (D)

3.2. Relationship among total BEF with DBH, Height, and Age of *Acacia* hybrid plantations

Figure 1 showed changes of BEF with stand characteristic parameters of *Acacia* hybrid plantations. Specifically, BEF decreased as increasing of DBH, H, and age. The BEFs dramatically decreased from age of two to age of six, corresponding to tree's height from 4 m to 15 m and the tree's DBH from 3 cm to 13 cm. The BEF tended to increase a little after age of six, height of 15 m and DBH of 13 cm. These results could reveal that smaller and younger trees had many branches and leaf biomass as compared to bigger and older ones. On the other hand, the results also suggested that smaller and younger trees were the greater dispersion and less scatter at mature and older trees. Moreover, the data dispersion of BEF strongly demonstrated that the DBH, H, and age were significantly correlated with the BEF.

3.3. Correlation matrix among BEF with DBH, height, and age

Table 3 showed a result of the correlation analysis between BEF and stand characteristic factors (DBH, height, and age). BEF and Correlation Coefficient (R) was significantly correlated with DBH, H, and age. The BEF had a strongly significant negative relationship with DBH (R = - 0.91), H (R = - 0.90), and age (R = - 0.82). Additionally, correlation relationship among DBH, H, and age were very significantly positive with their correlation coefficients greater than 96%.

Table 3. Correlation matrix among BEF, DBH, Height, and Age

Variables	Age	DBH	Height	BEF
Age	1	-	-	-
DBH	0.98	1	-	-
Height	0.96	0.98	1	-
BEF	-0.82	-0.91	-0.90	1

3.4. Construction of BEF models with tree growth criteria of DBH, Height, and Age

Table 4 presents statistical parameters of twelve fitted BEF models. The twelve models (as shown in Table 1) were used to fit models of BEF by basing on values of the measured DBH, Height, and Age. The adjusted coefficients of determination (R^2_{adj}) of the twelve fitted BEF models were mostly over 0.80, except for two models of # 6 and # 9. This result proved that the fitted BEFs had a high correlation with DBH, H, and Age. The fitted models of #10 and #12 had the highest R^2_{adj} values of 0.94 and 0.95, the highest negative AIC values of -133.59 and -137.67, the smallest RMSE values of 0.065 and 0.070, and the smallest SEE values of 0.069 and 0.073, respectively. Thus, models of #10 and #12 were two best fitted models that could be applied to estimate a value of BEF for any age of the *Acacia* hybrid plantations. Equations for two models are described as follows:

$$BEF = 1.99865 - 0.15400*DBH - 0.02123*H + 0.18210*A \text{ (Model \#10)}$$

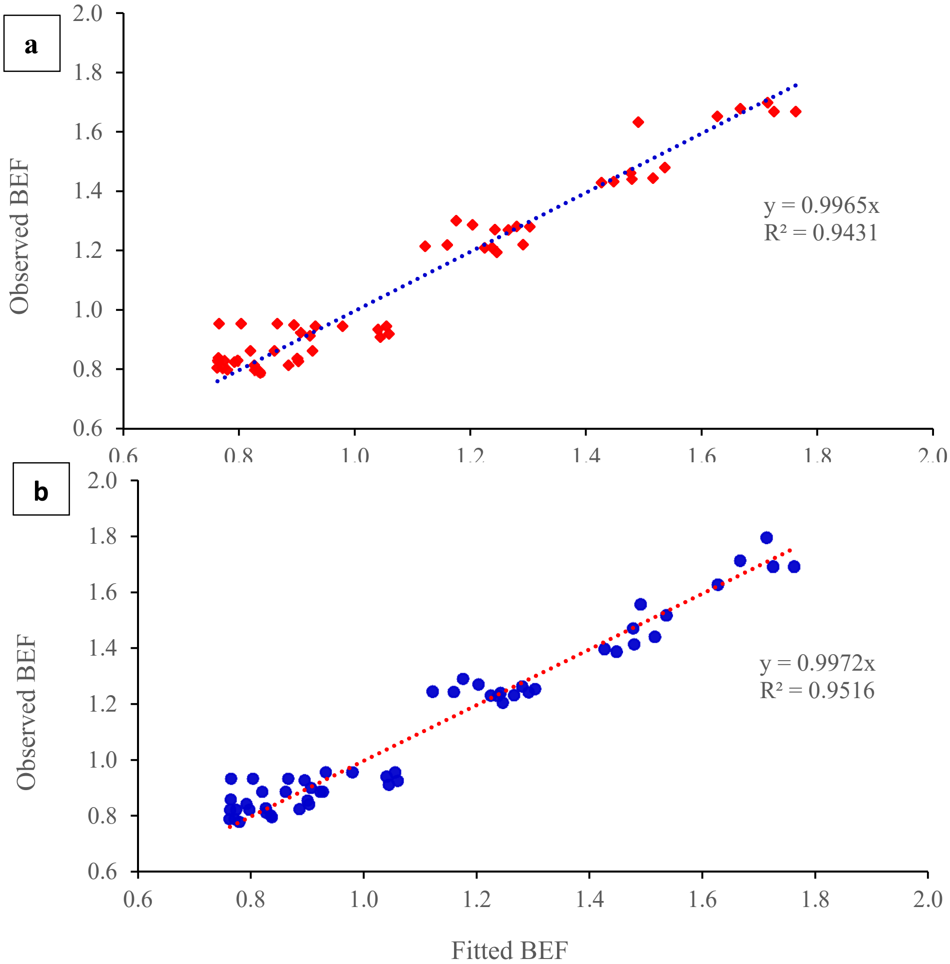
$$BEF = 3.01307 - 2.44459*\ln(DBH) - 0.10171*DBH - 2.06212*\ln(H) + 1.54556*\ln(DBH*H*A) \text{ (Model \#12)}$$

Table 4. Statistical parameters of twelve fitted BEF models

Model	Statistical parameters								
	m_1	m_2	m_3	m_4	m_5	R^2adj	SEE	RMSE	AIC
1	3.41282	0.50041	-	-	-	0.87	0.112	0.110	-109.39
2	3.55451	0.47026	-	-	-	0.81	0.132	0.129	-100.46
3	2.32314	0.45925	-	-	-	0.81	0.132	0.129	-100.38
4	2.52418	-0.61490	-	-	-	0.87	0.109	0.107	-110.84
5	2.63124	-0.60187	-	-	-	0.83	0.126	0.123	-102.96
6	1.99556	-0.53005	-	-	-	0.79	0.141	0.138	-96.94
7	2.07563	0.06020	-	-	-	0.86	0.113	0.111	-108.83
8	2.09200	0.04847	-	-	-	0.83	0.125	0.123	-103.36
9	1.90053	0.09571	-	-	-	0.73	0.157	0.154	-91.03
10	1.99865	-0.15400	-0.02123	0.18210	-	0.94	0.073	0.070	-133.59
11	2.38384	-0.19602	-	-	-	0.84	0.122	0.120	-104.61
12	3.01307	-2.44459	-0.10171	-2.06212	1.54556	0.95	0.069	0.065	-137.67

3.5. Validation of two best fitted BEF models

Figure 2 is a scattered plot that shows a linear one-to-one relationship of the observed BEF values from the measured data of *Acacia* hybrid plantations in the field and the fitted BEF values from the model of #10 (Fig. 2a) and the model of #12 (Fig. 2b). Values of two best fitted BEF models were strongly correlated with the observed BEF values. Correlation coefficients of this relationship for two models were very high and similar to each other, 99.63% for model of #10 and 99.68% for model of #12. This result confirmed that two BEF models of #10 and #12 are the best fitted with the practical data and could be selected for an estimation of the BEF value at any age of an *Acacia* hybrid (*A. auriculiformis* * *A. mangium*) plantation.



3.6. Biomass and carbon stocks of *Acacia* hybrid plantation

Table 5 showed the estimated results for the above-ground biomass, above-ground carbon stock and above-ground CO_2 equivalent of *Acacia* hybrid plantations.

Table 5. Biomass and C stocks of *Acacia* hybrid plantation

Age	Density (trees/ha)	Above-ground biomass (tons/ha)	Above-ground carbon stocks (tons/ha)	Above-ground CO_2 equivalent (tons/ha)
2	2100	9.7	4.9	17.8
4	1977	67.0	33.5	122.9
6	1783	133.0	66.5	244.1
8	1600	205.4	102.7	376.9
10	1460	244.6	122.3	448.8

Research results showed that the density was decreased with an increasing in the age of the *Acacia* hybrid plantations, in which the highest density was 2100 trees/ha at the age of 2. The density gradually decreased to 1783 trees/ha at the age of 6 and reached the lowest value of density at the age of 10 with 1460 trees/ha. Above-ground biomass, above-ground C stock and C sequestration rapidly increased as an increasing of the age. At the age of 2, the amounts of above-ground biomass, above-ground C stock and CO_2 equivalent in the *Acacia* hybrid plantation were 9.7, 4.9 and 17.8 tons/ha respectively, while these amounts reached the highest values at the age of 10 respectively corresponded to 244.6, 122.3 and 448.8 tons/ha for above-ground biomass, above-ground C stock and CO_2 equivalent.

4. DISCUSSION

In our study, the BEF value of *Acacia* hybrid plantations in Southeastern region of Vietnam ranged between 0.76 and 1.76 with an average BEF of 1.11 ton/m^3. The measured average BEF values in this study were in estimated range of many studies that were implemented in Vietnam as well as throughout the Southeast Asia [13, 23, 28-30]. Results of the study in Northeastern region [21] reported that the average value of BEF was 0.873, ranging from 0.725 to 0.915 for same species at the age of from 1 to 7 years. In general, the average value of BEF for *Acacia* hybrid plantations at the age of from 2 to 10 years in this study was significantly higher than this value by Xuan *et al.* (2012) [21]. This difference of average BEF value could be due to a number of collected samples, the growth phase and site conditions of *Acacia* hybrid plantations in different regions.

Traoré *et al.* (2018) [17] found that the BEF value of *Acacia mangium* plantations ranged between 1.21 and 1.66, while Mavouroulou (2012) obtained the BEF values between 1.04 and 3.88. The BEF values of *Acacia* hybrid plantations in this study were smaller than the default values for the tropical broad-leaf forest type with DBH >10cm ranged from 2.0 to 9.0 with the average value of 3.4, which was reported by IPCC (2003) [18]. Values of BEF in this study tend to decrease as a function of stand tree age, and to increase as growing stock density (volume of growing stock per ha), similar to many estimates obtained worldwidely from different studies [13, 21, 23, 28, 29]. This is due to an increasing ratio of merchantable volume to total volume. The decreasing of BEF value is rapid at low growth-stock densities or levels out for older stands and higher stand densities [9].

The results of this study also revealed that the BEF is significantly correlated with the age, diameter at breast height (DBH) and height of the *Acacia* hybrid plantations, in which the DBH is the most closely correlated with BEF. Our research result is similar to results that were found by Sanquetta et al. (2011) [28] that the BEF depended on age, DBH and height. Additionally, results of other researches showed that the BEFs of forests were age-dependent [23, 31], volume-dependent [5, 15], decreased with an increasing of age [21, 31]. Levy et al. (2004)[32] found that tree height was a better predictor than age. In general, BEFs vary with tree size (age, etc.) and change of tree populations over time [21-23, 31].

Above-ground biomass for Acacia plantations from observational data in this study were 9.7 – 244.6 ton/ha from 2 to 10 years. By using model of BEF from Zhang *et al.* (2012) [13], biomass vary 18.1 – 425.4 ton/ha. By utilizing the equations of model #10 and #12, an estimated biomass value at the age of 10 were 267.3 ton/ha for model #10 and 260.8 ton/ha for model #12 (Table 6).

Table 6. Comparison biomass of *Acacia* hybrid plantation by three different approaches

Age (year)	Practical biomass in this study (ton/ha) (1)	Biomass estimated from model #12 (ton/ha) (2)	Biomass estimated from model #10 (ton/ha) (3)	Biomass from Zhang et al. (2012) (4)	Difference of biomass between models 10, 12, and Zhang *et al.* (2012) with the practical biomass (%)		
					(2) & (1)	(3) & (1)	(4) & (1)
2	9.7	9.68	9.65	18.1	-0.23	-0.54	86.19
4	67.0	67.61	69.0	88.2	0.92	2.98	31.60
6	133.0	137.83	140.1	261.2	3.63	5.37	96.40
8	205.4	200.48	196.3	350.4	-2.40	-4.42	70.59
10	244.6	260.76	267.3	425.4	6.61	9.29	73.93
Average	**131.94**	**135.27**	**136.49**	**228.7**	**1.70**	**2.54**	**71.74**

Basing on the estimated results in Table 6, there was obviously a difference of estimates between the method of Zhang *et al.* (2012) [13] and the others. The percentage of increases between BEF value from method of Zhang et al. (2012) [13] to compare with fitted BEF of model #10 and fitted BEF of model #12 in this study were 71.74%, 2.54% and 1.70% respectively. The model of BEF offered by Zhang *et al.* (2012) was calculated by basing on the collected data from several different plantations of *Acacia* species, but not included any *Acacia* hybrid **(***A. auriculiformis* * *A. mangium*) plantations. Recent studies indicated that a value of BEF was depended on species to be planted, growth phase, and site index [22]. Therefore, estimates of BEF under specific conditions shall be considered. With the negligible difference of biomass between model #10 and #12 compared with the practical measured biomass, therefore it is concluded that models of #10 and #12 could be used to quickly calculate above-ground biomass and carbon stock of the Acacia hybrid plantations.

5. CONCLUSIONS

The results of this study revealed that the BEF value of *Acacia* hybrid plantations in the Southeastern region of Vietnam was strongly correlated with DBH, height, and age (adj $R^2 > 0.9$), in which an age of stand trees is highly associated with BEF. The mean BEF value of *Acacia* hybrid plantations was 1.11 ton/m^3, ranging from 0.76 to 1.76. Value of the BEF decreased as DBH, height, and tree age increased. The above-ground biomass, carbon stocks, and CO_2 equivalent for *Acacia* hybrid plantations at 10 years were 244.6 t/ha, 122.3 tC/ha, and 448.8 tCO_2/ha, respectively. Two best fitted models that could apply to estimate a value of BEF for any age of *Acacia* hybrid plantations include: BEF = 1.99865 - 0.15400*DBH - 0.02123*H + 0.18210*A; and BEF = 3.01307 - 2.44459*ln(DBH) - 0.10171*DBH - 2.06212*ln(H) + 1.54556*ln(DBH*H*A). Utilization of three methods as described in this study to estimate above-ground biomass for any *Acacia* hybrid plantations may have an overestimation or an underestimation. The results also indicated that use of the regression model is fundamental in obtaining reliable estimates of forest tree biomass, carbon sink and CO_2 equivalent, and that two best fitted models selected in this study could be applied to calculate the amounts of above-ground biomass, carbon stocks, and CO_2 equivalent values for *Acacia* hybrid plantations with any their ages.

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