Above-ground Biomass Allometric Equation and Dynamics Accumulation of *Eucalyptus Camaldulensis* and *Acacia* Hybrid Plantations in Northern Thailand

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Abstract- In order to supply biomass energy in Thailand, fast-growing trees like *Eucalyptus* and *Acacia* are large plantations in the region. However, there are few studies on related topics such as biomass growth versus time and tree partitioning. The objectives of the study are to develop biomass equations and characterize biomass dynamics accumulation for *E. camaldulensis*, *E. camaldulensis* coppice, and *A*. hybrid. The study plantation area is 960 hectares in Lampang and Lamphun province, Northern Thailand. The planted density is 1666 trees ha^{-1}. A total of 221 trees for destructive sampling were randomly selected from thirteen sites. Allometric biomass equations for tree components are developed by regressing the diameter at breast height (DBH), tree height (H) and a combination of these. The results show that DBH alone is an optimal predictor variable for all studied species. However, the combination of DBH and H is more accurate than DBH alone. The models show that the total estimated above-ground biomass (AGB) production is 62.78 t ha^{-1} and 48.87 t ha^{-1} at the age of 5 years of *E. camaldulensis* and *A*. hybrid, respectively. The total estimated AGB production of *E. camaldulensis* coppice is 18.21 t ha^{-1} at 3 years of age. The equations developed in the study can be used to estimate the growth of the three species under the same growing conditions: topography, tree growth dimensions, and plantation density.

Keywords Above-ground biomass, Allometric equations, *Eucalyptus camaldulensis*, *Acacia* hybrid.

1. Introduction

Thailand's use of fossil fuels to provide energy generation cannot be sustained for the long term due to limited reserves, and because of their emissions lead to environmental degradation and climate change. Therefore, Thailand has developed the Alternative Energy Development Plan (AEDP 2015) with the goal of using renewable energy, increasing from 12 to 30% of final energy consumption in 2036 [1]. Renewable energy is an attractive alternative to fossil fuels due to economic feasibility [2] and environmental sustainability advantages [3]. Especially, biomass is an energy resource with high energy potential in many countries [4, 5] and utilization in power plant and industry [6]. Biomass has become an interesting renewable source of energy worldwide in recent years, since it can be transformed into three phases of fuel: gas, liquid and solid [7] and can be produced from various biomass feedstocks, including forest, agricultural residues, short rotation forest plantations and other organic waste streams [8]. Moreover, utilization of biomass for power plants is lower environmental impact than fossil fuel thermal power plants over five times [9]. The goal of Thailand's AEDP 2015 for electricity and thermal production from biomass was determined from 2014 to 2036, increasing from 2452 MW to 5570 MW and 5144 ktoe to 21000 ktoe, respectively. As Thailand is an agricultural country, there are many agricultural residues, but these are still not enough to supply this plan. Therefore, it is necessary to find a new alternative by planting fast-growing trees as an energy crop [1].

Usually, forest plantation management for solid wood products or fiber production that requires long-term rotations of from 10 to 100 years depends on the species and plantation site, but fast-growing tree plantation for bioenergy would reduce the rotation length to 5 years or less [10]. *Eucalyptus* and *Acacia* species are widely used at present as plantation crops because of their short rotations and high productivity [11, 12], and they adapt well to a variety of plantation sites, while their management is uncomplicated compared with other regular forest species [13]. Furthermore, *Eucalyptus* can accommodate stump sprouting (coppicing), which means repeated harvesting at short time intervals (normally 3 years) over their cycle [14, 15].

The development of accurate biomass estimation has increased in recent years due to its importance in assessing productivity and carbon content for use as bioenergy [16]. It can be estimated by direct or indirect methods. The direct method measures the biomass by destructive sampling and weighing trees in the field, which are time-consuming and expensive, while the indirect method is non-destructive and involves developing allometric relationships, which are less time-consuming and more cost-effective than direct measurements [17]. DBH and H are the most commonly used variables for biomass estimation [18]. Most biomass estimation equations are based on the allometric model ($y = k\,x^a$), where k and a are the parameters, x is the variable of the tree dimension, and y is the estimated biomass [19, 20]. The total AGB is always estimated but for different objectives; the separation of each component is required [21].

In Thailand there are few studies about fast-growing tree biomass allometric equations and dynamic accumulation production based on industrial plantation data. Most of them have been developed on an experimental scale and used data from publication [22]. The industrial plantation data in turn provides valuable information for decision makers to encourage fast-growing tree plantation in line with Thailand's AEDP.

The objectives of this study were to develop the AGB allometric equation for leaves, branches, bark, stem, and total AGB by using the relationship between the AGB production and tree dimensions, consisting of the diameter at breast height and height, to characterize the biomass dynamics accumulation of *Eucalyptus camaldulensis*, *Eucalyptus camaldulensis* coppice and *Acacia* hybrid plantation in Northern Thailand.

2. Materials and Methods

2.1. Site Study and Management

The study site (Fig. 1) was the Sahacogen Green Co., Ltd. plantations (17°42′–18°68′N, 98°68′–99°77′E), covering Lamphun and Lampang provinces (northern region of Thailand). The study site region has a wide plains topography in which hills and river plain areas were observed. From the observation, the soils are classified as sandy loam and sandy clay loam. The altitude is 268 m a.s.l. According to the meteorological data, the main rainy season is form June to August, average annual rainfall is approximately 1323 mm and temperature is 26.2 °C.

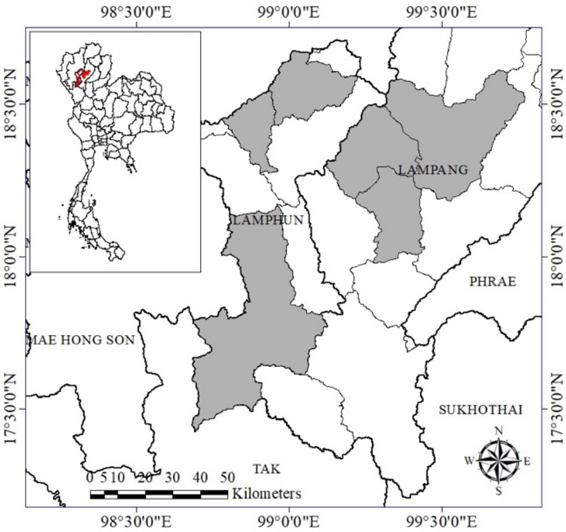


Fig. 1. The study location with *E. camaldulensis* and *A.* hybrid plantation in Lamphun and Lampang provinces, Thailand.

2.2. Plantation Management

E. camaldulensis and *A.* hybrid have been planted since 2008 with spacing of 2 m × 3 m and approximately 1666 trees per hectare, with the trees planted in monoculture plots. Irrigation was by rainfall only, while weeding was performed every year except during the harvesting period. Plantation management for *E. camaldulensis* was managed as coppices after the first rotation harvest at the end of every 4th year followed by 3 rotations every 3 years, and stump removal was conducted at the end of the 13th year. The number of coppices per stump after harvesting was thinned to not more than 3 stems per stump. *A.* hybrid was harvested at the age of 5 years, after which stumps were removed.

2.3. Experimental Design and Measurement

This study was carried out at 13 sites in northern Thailand with three species *E. camaldulensis*, *E. camaldulensis* coppice and *A.* hybrid. To obtain data on growth variation, all species in three 20 m × 30 m experimental plots, randomly located in each stand and with ages ranging from 1 to 6 years, were selected to study the AGB production. DBH (at 1.3 m above ground) and H were measured using a measuring tape and measuring pole, respectively (Table 1). Ten to twelve trees per stand, proportionally distributed along the range of DBH in each age group, were felled for biomass sampling. AGB and the stand basal area were expressed on a per hectare basis by assuming a tree planting density of 1666 trees per hectare. Biomass production was estimated using the best fitting allometric models.

Table 1. Summary statistics of the experimental plots stand characteristics of *E. camaldulensis*, *E. camaldulensis* coppice, and *A*. hybrid plantation in Northern Thailand.

Species	Age (years)	N Stumps	N Coppices	DBH (cm)	QMD (cm)	BA (m^2 ha^{-1})	H (m)
E. camaldulensis	1.08	283	–	2.24	2.44	0.74	3.00
	1.50	295	–	4.37	4.40	2.49	5.49
	2.00	270	–	5.42	5.65	3.76	7.59
	2.75	275	–	6.69	6.79	5.53	9.65
	3.42	294	–	7.54	7.50	7.21	11.53
	4.17	271	–	9.37	9.52	10.71	13.54
	5.08	273	–	10.06	10.28	12.59	15.34
E. camaldulensis coppice	0.58	278	754	1.79	1.90	1.18	3.04
	0.83	267	670	1.91	1.91	1.06	3.40
	1.50	254	619	2.57	2.53	1.73	4.63
	2.25	269	633	3.46	3.25	2.92	5.62
	2.50	263	582	3.68	3.44	3.01	6.20
	3.17	256	523	4.38	4.07	3.77	7.35
A. hybrid	1.05	288	–	2.02	2.11	0.56	2.66
	1.98	284	–	4.04	4.28	2.27	4.75
	2.57	286	–	5.14	5.40	3.64	6.20
	3.07	279	–	6.50	6.77	5.59	7.19
	3.73	285	–	7.51	7.64	7.26	8.57
	4.82	289	–	8.99	9.24	10.76	11.07
	5.73	283	–	9.64	9.95	12.22	11.83

Note: N is stand density in three 20 m × 30 m experimental plots; DBH is the mean diameter at breast height; QMD is the shoot quadratic mean diameter; BA is the stand basal area; H is the mean total tree height and coppices are harvested stands after the first rotation.

Table 2. Stand characteristics of 221 destructively sampled trees for fitting biomass equations.

Components	Min	Max	Mean	Std. dev.
DBH (cm)				
E. camaldulensis	3.18	15.28	7.83	2.80
E. camaldulensis coppice	0.38	11.30	4.53	3.10
A. hybrid	1.27	13.62	6.82	2.84
H (cm)				
E. camaldulensis	4.90	18.15	11.83	3.29
E. camaldulensis coppice	2.11	13.17	6.63	3.05
A. hybrid	2.91	16.01	8.83	3.26
Stem (kg dry weight)				
E. camaldulensis	1.06	63.70	19.09	15.95
E. camaldulensis coppice	0.13	43.80	7.25	10.93
A. hybrid	0.18	60.84	13.53	14.22
Total AGB (kg dry weight)				
E. camaldulensis	1.62	81.38	24.21	19.93
E. camaldulensis coppice	0.23	52.32	9.66	13.41
A. hybrid	0.45	81.24	19.39	18.74

2.4. Biomass Partitioning and Allometric Models

To avoid the edge effect on the tree dimension variable, destructively sampled trees of all species from the experimental plots for each site were taken from the center of the plantation areas [23]. DBH was measured before harvesting. After felling the sampled trees, H was measured using a measuring tape and they were separated into stem, bark, branch and leaves components using a bow saw. These components and selected representative subsample fresh weights were weighed on a balance in the field. Subsamples of each component were oven dried at 70 °C to a constant weight. The dry weight of each component was calculated from its moisture content. Data from 221 destructively sampled trees, including 72 *E. camaldulensis*, 70 *E. camaldulensis* coppice and 79 *A*. hybrid, were collected to develop biomass allometric equations, shown in Table 2, and the relationship between H and DBH is presented in Fig. 2a – 2c.

2.5. Statistical Analysis

The biomass component for different stand ages and coppice-shoot ages were carried out by one-way analysis of variance (ANOVA), and a correlation analysis was proceeded using the Spearman's rank correlation coefficient.

Regression allometric models were used for analysis after logarithmic transformation of the dry weight to evaluate the relationship of the biomass components with independent variables, such as DBH, H and a combination of these variables. Non-linear models were transformed to linear models by taking the logarithm, using the following modelsAll illustrations must be supplied at the correct resolution:

$$W = a + b(DBH) \quad (1)$$
$$W = a(DBH)^b \quad (2)$$
$$W = a(DBH + 1)^b \quad (3)$$
$$W = \mathrm{a}{\cdot}H^b \quad (4)$$
$$W = a + b{\cdot}H + c{\cdot}H^2 \quad (5)$$
$$W = a\{(DBH){\cdot}H\}^b \quad (6)$$
$$W = a\{(DBH)^2{\cdot}H\}^b \quad (7)$$
$$W = a(DBH)^b{\cdot}H^c \quad (8)$$

The best model was assessed on the highest adjusted coefficient of determination (R^2_{adj}), the lowest standard error of the estimation and p-value.

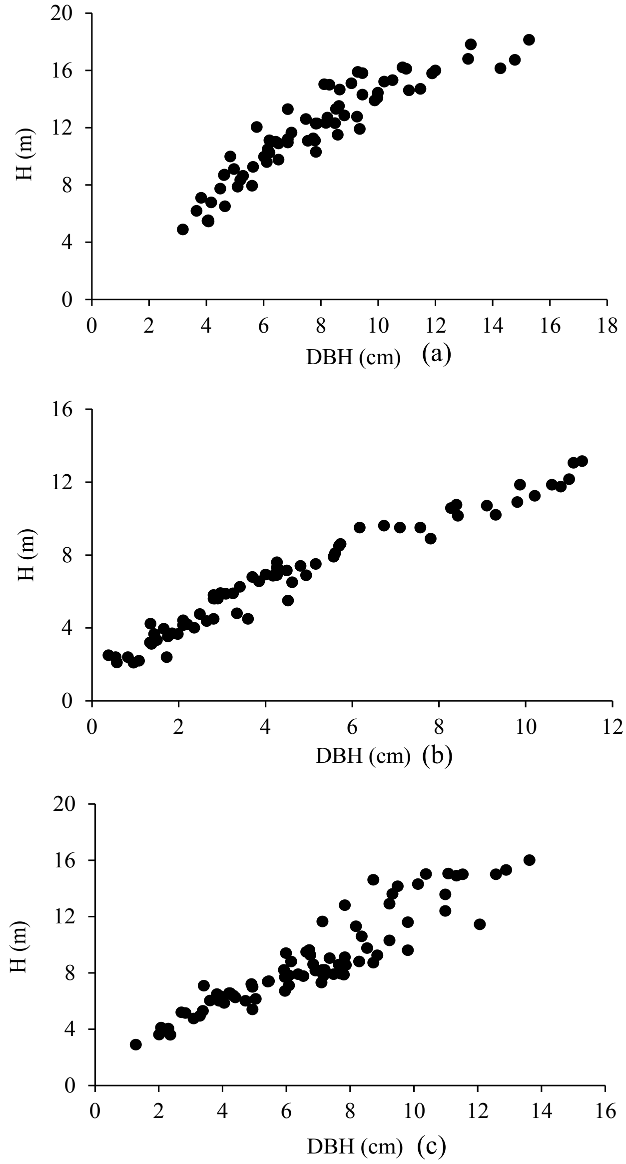


Fig. 2. The relationship between total tree height (H) and diameter at breast height (DBH) of destructive sample (a) *E. camaldulensis*, (b) *E. camaldulensis* coppice and (c) *A*. Hybrid.

3. Results and Discussion

3.1. Above-ground Biomass Structure

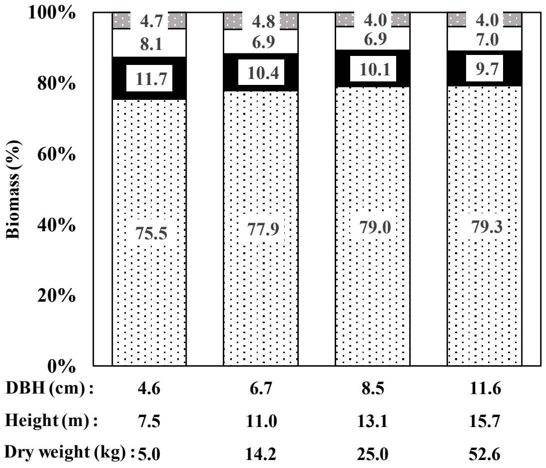
The distribution of the AGB components is divided into four parts (stem, bark, branch and leaves) and variations of these according to the tree dimensions (DBH, H and dry weight) for each species are presented in Figs. 3. There is a trend towards increasing stem biomass for all tree species as the tree dimensions increase [24]. Especially for *E. camaldulensis* coppice, the stem percentage increases rapidly from 51.0% to 78.9%, while for the bark, branch and leaves biomass the percentage decreases as the dimensions increase (Fig. 3b). Observing the different species, the largest portion of AGB is stem and bark, except for *A*. hybrid, for which it is branch. For *E. camaldulensis*, the largest proportion of AGB is concentrated in the stem, between 75 and 80% [25] regardless of the tree dimensions, and the percentage of leaves, which is also outstanding, amounts to about 4.0% of the total biomass (Fig. 3a). This compares well with 3% given by Muñoz et al. [26] and 4% given by Peichl et al. [27], while for other species, it is not less than 6.6%. *E. camaldulensis* coppice and *A*. hybrid demonstrate high proportions of branch and leaves, but these continuously declined from 35.2% and 32.8% in young trees to 12.7% and 16.1% in mature trees, respectively (Fig. 3c). The proportion of bark was relatively stable along the growth cycle for both *E. camaldulensis* and *A*. hybrid [14].

The stem wood proportion was found to increase with age, whereas leaves and branches decrease [27], but the proportion of bark is variable depending on the tree species [24]. Hence, biomass underestimation or overestimation at young or mature stands may result from the variability of the biomass expansion factor [28, 29].

Figs. 4 show the relationship of AGB as a function of DBH and H for estimating the AGB of *E. camaldulensis*, *E. camaldulensis* coppice and *A*. hybrid, respectively. DBH shows a strong correlation with AGB for *E. camaldulensis* and *A*. hybrid, but in the case of *E. camaldulensis* coppice, H shows a stronger correlation than DBH. In the destructively sampled *E. camaldulensis*, *E. camaldulensis* coppice and *A*. hybrid biomass, the distribution of total AGB ranged from 1.62 to 81.38 kg stem^{-1} (Fig. 4a), 0.16 to 52.32 kg stem^{-1} (Fig. 4b) and 0.45 to 81.24 kg stem^{-1} (Fig. 4c), respectively.

The regression models used to estimate the AGB components which included the DBH variable only provided the best fit between 85.3 to 97.2% compared with the H variable alone, which demonstrated between 79.7 to 93.3% for *E. camaldulensis*, between 89.1 to 95.4% compared with the H variable alone, which demonstrated between 83.6 to

97.4% for *E. camaldulensis* coppice and between 81.6 to 93.9% compared with the H variable alone, which demonstrated between 71.3 to 89.2% for *A.* hybrid.



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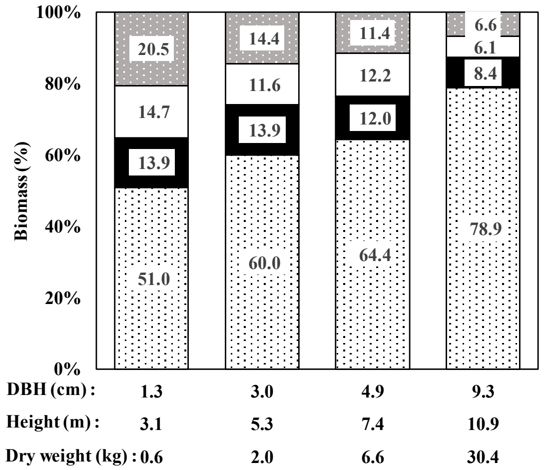

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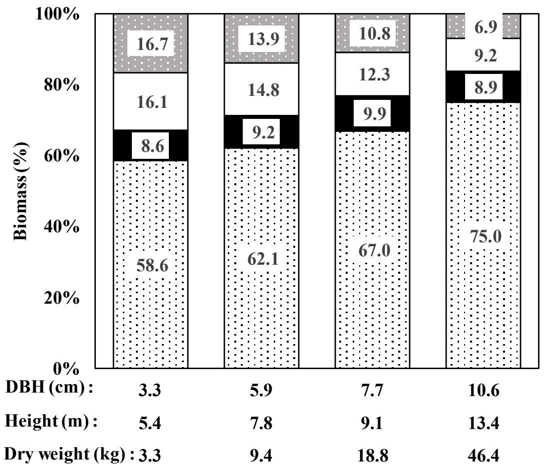
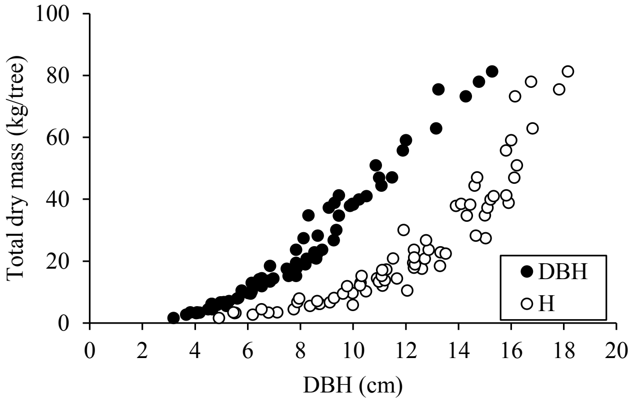


(c)

Fig. 3. Distribution of AGB components (□ Stem, ■ Bark, □ Branch and ■ Leaves) divided into four parts by average DBH, height and dry weight of (a) *E. camaldulensis*, (b) *E. camaldulensis* coppice and (c) *A.* hybrid.



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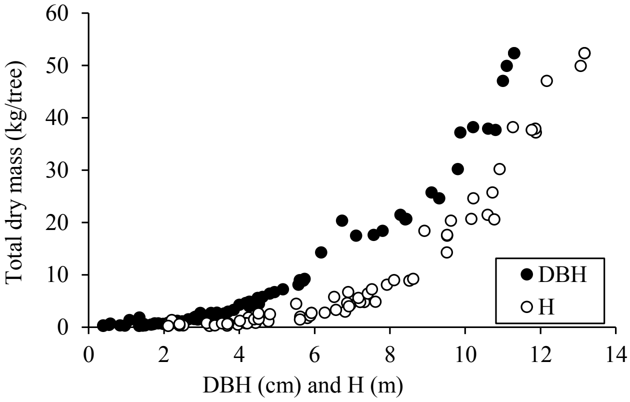

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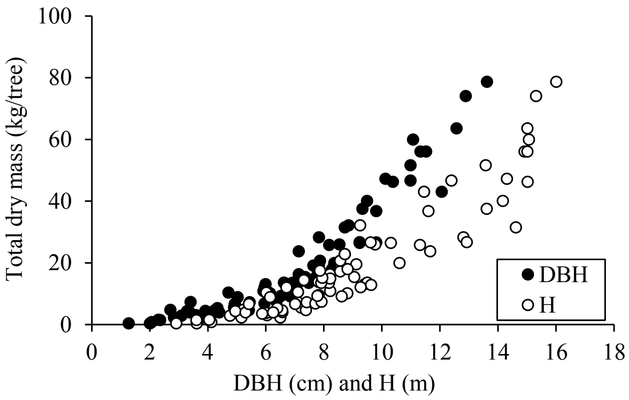


(c)

Fig. 4. Distribution of diameter at breast height (DBH), total tree height (H) and total dry mass for the destructively sampled trees of (a) *E. camaldulensis*, (b) *E. camaldulensis* coppice and (c) *A.* hybrid.

3.2. Biomass Allometric Equations

The best allometric models for estimating the AGB of *E. camaldulensis*, *E. camaldulensis* coppice and *A.* hybrid, which are fast-growing trees for plantations to supply the energy sector in Thailand was developed in this study. This would provide helpful information for the large-scale estimation of biomass since the allometric models have been developed from large-sized plantation data.

The best fitting allometric models for estimating the AGB of different components based on DBH and H with R^2, R^2_{adj}, standard error of the estimation and *p*-values are given in Table 3. The allometric models showed that the tree dimensions, such as DBH, H and a combination of these variables, could be used as predictor variables. DBH was the major predictor variable for all tree species and tree biomass components since it indicated a strong correlation ($p < 0.001$, $R^2_{adj} \geq 0.816$) [27, 30–32]. Furthermore, measuring DBH is easier in the field and has a lower operating cost than other tree variables [13] and the diameter has a lower measurement error, normally less than 3%, while height measurement error can be 10–15% [33]. Nevertheless, the integration of DBH and H ensured even better accuracy of the biomass allometric equations [32, 34]. However, the results in this study showed that using H alone in Eq. (5) was the best variable to describe the biomass production for the total AGB of *E. camaldulensis* coppice, with R^2_{adj} of 0.974. If it is not time-consuming and is practically easy to construct, using only DBH in Eq. (3) as the predictor variable is sufficiently accurate, with R^2_{adj} of 0.954.

In this study, the general allometric models shown in Eq. (1)–(8) were developed for estimating the AGB of *E. camaldulensis*, *E. camaldulensis* coppice and *A.* hybrid, which indicated a good fit ($p < 0.001$, $R^2_{adj} = 0.816–0.987$). This showed that strong estimates of AGB for these species can be performed in different locations using general allometric regression models, which are not necessarily site-specific [22]. Thus, the site factor can be overlooked because it has less impact on the biomass allometric equation [35].

Leaves are temporary tissue [36], removing branches and trimming the crown are commonly practices in agricultural topography to reduce competition with other trees [27]. Therefore, the relationship between the leaves biomass with DBH and H was less declared than between the stemwood biomass and DBH and H. As a result, the biomass production of leaves and branches cannot be precisely estimated using DBH, partly due to the transient nature of these components [36]. The amount of biomass in small trees is usually overestimated. With increasing tree size, the tendency to overestimate is decreased [19]. A similar finding was reported by Kuyah et al. [37], who indicated that it is difficult to precisely estimate the biomass of small trees. Biomass was overestimated by between 10 and 48% using the allometric equations, while estimating biomass of the smallest trees strongly affects the value of allometric coefficients [38].

Regarding the allometric models for estimation of the total above ground biomass for all 3 species with the best fit, an improved fit was noticed when going from H as the predictor variable to DBH and the integration of these. The R^2_{adj} for the total AGB estimation rose from 0.933 via 0.972 to 0.987. This finding was corresponded with Santos et al. [11] reported that the predictive potentiality of allometric biomass estimation models for *Eucalyptus* and *Acacia* increased when H and DBH were combined as predictor variables. In addition, our study showed that a simple weight function (DBH + 1) in Eq. (3) can correct a large range of DBH affected by possible curvilinearity [22, 39] with a stronger correlation ($R^2_{adj} = 0.963$) for estimating the total AGB of all 3 species.

3.3. Tree Growth and Above-ground Biomass Production

The mean DBH of *E. camaldulensis* was greater than *E. camaldulensis* coppice and *A.* hybrid along the growth cycle from 1 to 5 years. At 3 years, the mean DBH of *E. camaldulensis* were approximately 14.7% and 42.1% higher than *A. hybrid* and *E. camaldulensis* coppice, respectively. At 5 years, the mean DBH of *E. camaldulensis* was greater than *A.* hybrid by approximately 9.1% (Fig. 5a). Fig. 5b shows the mean height of *E. camaldulensis*, which was equivalent in all species at 1 year. After that, with the highest growth rate, and at 3 years, *E. camaldulensis* trees were approximately 32.3% and 33.5% higher than the *A.* hybrid trees and *E. camaldulensis* coppice trees, respectively. At 5 years, the mean height of *E. camaldulensis* was greater than *A.* hybrid by approximately 27.7%.

Paula et al. [40] reported that fertilizing with nitrogen (N) in *Eucalyptus* planting leads to increased growth, and in mixed plantations of *Eucalyptus* and *Acacia* it has the result that the mean DBH and H are greater than under *Eucalyptus* monoculture, since *Acacia*, a nitrogen-fixing tree and its roots, seems to allow significant quantities of biologically fixed N to become available for the *Eucalyptus* trees [41, 42]. However, in higher density stands, the *Eucalyptus* DBH was similar to that under monoculture [11].

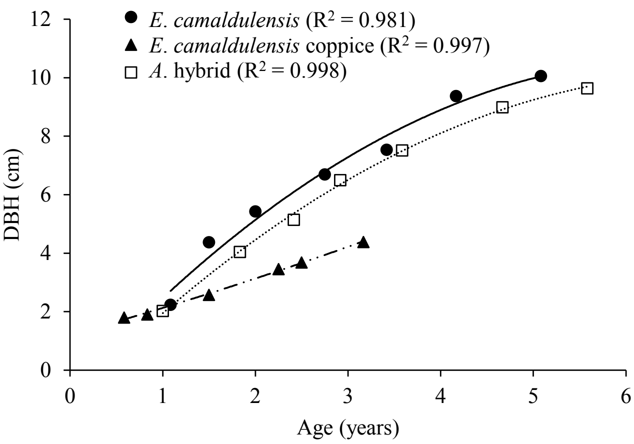
The best fitting allometric models in Table 3 and the tree dimensions in Figs. 5 were used to estimate the average total AGB and stemwood (stem + bark) biomass production as shown in Figs. 6. At 3 years, we found that for *E. camaldulensis* the total AGB production was higher than for *A.* hybrid and *E. camaldulensis* coppice. Moreover, at this age, the *E. camaldulensis* stemwood production was on average, 55.7% and 65.9% higher than *A.* hybrid and *E. camaldulensis* coppice, respectively, as shown in Fig. 6a. At 5 years of age, *E. camaldulensis* still exhibited a total AGB that was greater than *A.* hybrid. Furthermore, the stemwood production of *E. camaldulensis* yielded 47.2%, which was higher than *A.* hybrid as shown in Fig. 6b.

In this study, the *E. camaldulensis* stemwood production was higher than *A.* hybrid and it also has short rotations of coppicing (*E. camaldulensis* coppice) from the stump sprout reproduction in coppice-regeneration [14, 15]. The stump sprouting ability is an advantage to reduce the cost of biomass production. For *Eucalyptus* plantations, the cost of the processing of seedlings, soil preparation and conditioning and cultivation consumed 1308.28 USD ha^{-1} at the 1st crop rotation. However, the plantation cost would be reduced to 527.34 USD ha^{-1} if the plantation were managed as coppice at the 2nd crop rotation [43].

Table 3. Best fit of allometric models to estimate above-ground tree biomass components for *E. camaldulensis*, *E. camaldulensis* coppice and *A*. hybrid plantation in Northern Region of Thailand.

Components	Models	R^2	R^2_{adj}	S.E.E.	*p*-values
Leaves					
E. camaldulensis	$= -1.121 + 0.272(DBH)$	0.855	0.853	0.316	<0.001
E. camaldulensis coppice	$= -0.339 + 0.247(DBH)$	0.892	0.891	0.268	<0.001
A. hybrid	$= -0.701 + 0.361(DBH)$	0.818	0.816	0.487	<0.001
Branches					
E. camaldulensis	$= 0.004(DBH + 1)^{2.642}$	0.912	0.911	0.491	<0.001
E. camaldulensis coppice	$= -0.322 + 0.232(DBH)$	0.903	0.902	0.237	<0.001
A. hybrid	$= 0.022(DBH)^2 \cdot H^{0.727}$	0.884	0.882	0.627	<0.001
Bark					
E. camaldulensis	$= 0.009(DBH)^{1.800} \cdot \mathrm{H}^{0.670}$	0.971	0.970	0.525	<0.001
E. camaldulensis coppice	$= 0.633 - 0.314 \cdot H + 0.044 \cdot H^2$	0.966	0.965	0.205	<0.001
A. hybrid	$= 0.006\{(DBH)^2 \cdot H\}^{0.894}$	0.939	0.938	0.320	<0.001
Stem					
E. camaldulensis	$= 0.027(DBH)^{1.625} \cdot H^{1.212}$	0.987	0.987	4.184	<0.001
E. camaldulensis coppice	$= 10.062 - 4.842 \cdot H + 0.551 \cdot H^2$	0.972	0.971	1.870	<0.001
A. hybrid	$= 0.044\{(DBH)^2 \cdot H\}^{0.894}$	0.939	0.939	2.171	<0.001
Total AGB					
E. camaldulensis	$= 0.045(DBH)^{1.692} \cdot H^{1.045}$	0.987	0.987	4.985	<0.001
E. camaldulensis coppice	$= 10.639 - 5.201 \cdot H + 0.630 \cdot H^2$	0.974	0.974	2.145	<0.001
A. hybrid	$= 0.102\{(DBH)^2 \cdot H\}^{0.825}$	0.949	0.948	2.830	<0.001
All 3 species	$= 0.046(DBH + 1)^{2.107}$	0.963	0.963	7.012	<0.001

Where each component is the dry weight biomass (kg), *DBH* is the diameter at breast height (cm), *H* is the tree height (m). R^2_{adj} is the adjusted coefficient of determination, S.E.E. is the standard error of the estimates.



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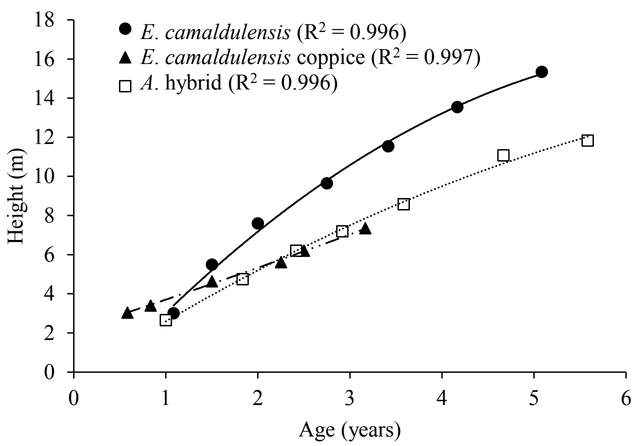
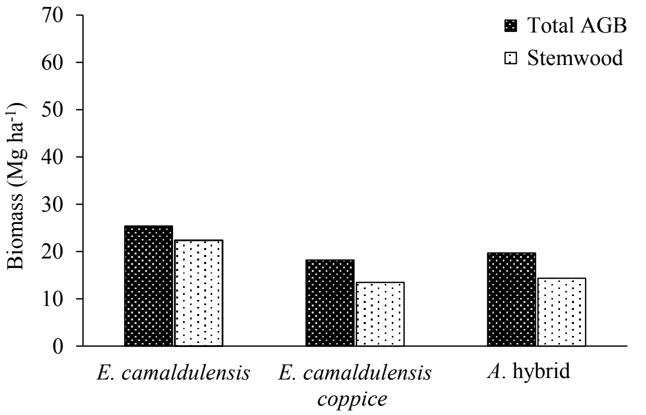


(b)

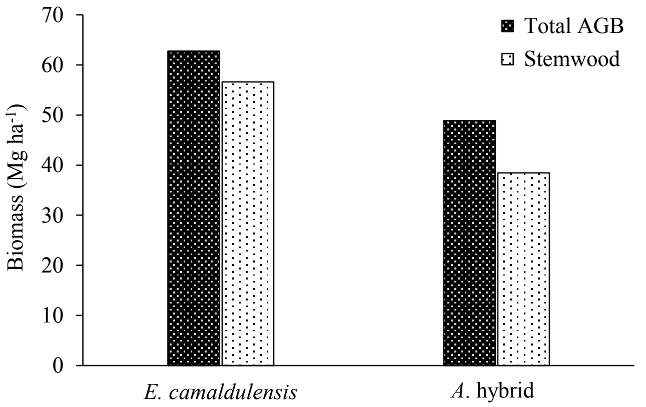
Fig. 5. The dynamics accumulation of the mean (a) DBH and (b) height of *E. camaldulensis*, *E. camaldulensis* coppice and *A*. hybrid plantations in the North of Thailand.

The soil of this plantation site possibly had a low capacity to provide N for *E. camaldulensis*, thus exhibiting a fairly low stemwood production of 62.78 Mg ha^{-1} at 5 years, compared with 65 Mg ha^{-1} with 3 m × 3 m spacing in the study by Santos et al. [11]. Water was unlikely to be an essential limiting factor for the biomass production of *Eucalyptus*, but the plantation with mineral N fertilization increased the biomass production from 65 to105 Mg ha^{-1} [11, 44].

A mixed plantation is an interesting approach to improving the biomass production capacity. Bauhus et al. [45] reported that a corporate plantation of *Eucalyptus* and *Acacia* had a higher tree dimension growth rate at 3–4 years after planting. A similar report by Santos et al. [11] indicated that stemwood production in corporated stands of *Eucalyptus* (50%) and *Acacia* (50%) at 60 months of age was about 13% and 46% higher than monoculture of *Eucalyptus* and *Acacia*, respectively.



(a)



(b)

Fig. 6. Average total AGB and stemwood (stem + bark) biomass production of *E. camaldulensis*, *E. camaldulensis* coppice and *A*. hybrid at (a) 3 years and (b) 5 years with 2 m × 3 m spacing.

4. Conclusion

The combination of DBH and H was more accurate than using single variables to estimating the AGB for *E. camaldulensis* and *A*. hybrid, but H alone showed the best fit for *E. camaldulensis* coppice. However, using only DBH as a predictor variable was more cost-effective and less time-consuming, while still being sufficiently accurate, with $R^2_{adj} \geq 0.939$ for all three species. The stemwood production of *E. camaldulensis* was higher than *A*. hybrid by about 47.2% at 5 years of age. Moreover, for *E. camaldulensis,* the advantage is that it has a sprouting ability after harvest.

The largest proportion of AGB for all three species is the stem, amounting to about 75–79% at mature stands, followed by bark, branches and leaves, respectively.

Regarding the AGB productivity of stemwood at 3 years of age, *E. camaldulensis* was higher than *A*. hybrid and *E. camaldulensis* coppice, respectively, and at 5 years *E. camaldulensis* still exhibited greater stemwood production than *A*. Hybrid.

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