DETERMINING AN APPROPRIATE AGE FOR ESTIMATING SITE INDEX OF *Acacia hybrid* PLANTATIONS IN SOUTHEASTERN VIETNAM

TRAN THI NGOAN[1] AND NGUYEN TAN CHUNG[2*]

[1]*Vietnam National University of Forestry, Dong Nai Province, Viet Nam*
[2]*Faculty of Biological Sciences, Nong Lam University, Ho Chi Minh City, Ho Chi Minh, Viet Nam*

Received 5 April 2018/Accepted 21 January 2020

ABSTRACT

This article documents the research results of a site index classification for *Acacia* hybrid plantations in Dong Nai Province. The objectives of this study were to 1) determine a baseline age for *Acacia* hybrid plantations to establish their site indices and 2) develop site index curves for *Acacia* hybrid plantations. Three standard plots were established for each age group of 1-10 years with 111 trees per plot of which 108 trees were measured for the determination of tree growth criteria. The other three trees were cut for the tree truncation estimate, and were excluded in the computation of tree growth criteria. In this study, the site index (SI) for *Acacia* hybrid plantations was divided into three levels based on the mean total heights of the dominant trees; Levels I (24 m), II (20 m), and III (16 m). The heights of the 108 trees were used to build the SI functions, and the three truncated trees were used to examine the possibilities of the SI functions. Research results showed that the appropriate baseline age of *Acacia* hybrid plantations at Dong Nai Province is 8 years. Moreover, in order to improve the effectiveness of *Acacia* hybrid plantation businesses, the owners should focus on growing plantations at site index levels of I or II.

Keywords: *Acacia* hybrid plantations, curve of site index, dominant trees, site index

INTRODUCTION

Climate change has negatively affected human and environmental health, particularly forest ecosystem health (IPCC 2000). Tropical rainforest ecosystems are one of the most important carbon sinks on the earth, playing a very critical role in balancing the global carbon cycle and CO_2 concentration (Chaiyo *et al.* 2011). As such, on forest biomass and carbon sequestration researches are very relevant in forest management and planning, as well as biomass energy use (Brown 2000 & 2002; Zianis *et al.* 2005). Moreover, biomass changes are associated with increases in forest ecosystem growth and rates of carbon absorption and emission (FAO 2009). A forest population ratio of biomass to carbon intensity depends on an age and site index (Nguyen & Tran 2016). An accurate estimation of forest biomass is an important factor in assessing the global carbon cycle (Chavé *et al.* 2005).

Several studies are interested in determining the mechanisms for worldwide carbon sequestration in different environments (Bouman *et al.* 1999). It is therefore, necessary to develop appropriate methods for surveying and evaluating forest biomass and carbon stocks (Chambers *et al.* 2001; Brown 2002, Chavé *et al.* 2005). Several studies also developed mathematical models for the estimation of forest productivity (Dong 1974; Nguyen & Dao 1999; Vu 2005 & 2012) and biomass functions (Vien 2008: Bao 2010; Vu & Vo 2011; Nguyen 2012; Dang 2014; Nguyen & Tran 2016) for timber trees and different types of natural forests. Although a few studies have focused on the site index curves of *Acacia mangium* Willd (Krisnawati *et al.* 2010; Lumbres *et al.* 2018), very limited information are available on biomass estimation of *Acacia* hybrid

*Corresponding author, email: ntchung@hcmuaf.edu.vn

plantations at various tree ages and soil site indices. Therefore, it is essential to predict *Acacia* hybrid plantation biomass to determine some functions based on different site indices.

The forest soil site index or soil productivity is a criterion for evaluating the site suitability for forest productivity (Nguyen & Dao 1999). Soil site quality (or productivity of a soil site) reflects the productivity capacity of a forest, which might change due to the effects of over-exploitation, fire, fertilizer application and/or soil erosion (Clutter *et al.* 1983). Site quality is determined through forest growth and yield, mean annual increment (MAI) and periodic annual increment (PAI) by site index (SI) and growth intercept (GI) methods (Clutter *et al.* 1983; Larsen 1999). SI can be estimated directly based on the average height of dominant trees (H_0) associated with a baseline age (A_0) (Monserud 1984). SI values also depend on tree species and is determined as functions of H_0 or GI (Monserud 1984; Larsen 1999; Vu 2005). The selection of a baseline age for a tree species is dependent on the life cycle (choosing a period at which population growth does not depend on species density) or business cycle (Monserud 1984; Larsen 1999).

The site index is determined by three different methods (Monserud 1984; Larsen 1999). The first method involves the construction of a site index population curve, which has been commonly used since the 1940s. This method is based on the related function of $H_0 = f(A_0)$ to construct a site index curve. The second method is based on selecting pairs of H_0 and age and defining the function $H_0 = f(A)$, where A is the age of a forest. Therefore, site index curves have different shapes by applying different functions. The third method involves truncation of individual trees, using site index curves based on results of tree truncation. This method was created in the 1980s and has been widely applied ever since. In general, each method gives a unique interpretation result (Monserud 1984; Larsen 1999; Vu 2005 & 2012). The SI curve converts H_0 at a baseline age (A_0) to H_0 at a matured age of trees (A). SI curves are usually constructed as tree growth functions related to mature ages; in other words, they are based on data pairs of H_0/A. A suitable SI curve must be fitted by mathematical, statistical methods and must be chosen based on statistical tests (Larsen 1999; Vu, 2005 & 2012).

Some researchers have studied the planting and breeding of *Acacia* hybrid species in Vietnam (Le 2000). The mature age of *Acacia* hybrid plantations in southern Vietnam is eight years (Nguyen *et al.* 2006). Nguyen et al. (2020) records the total area of *Acacia* hybrid plantations in Dong Nai Province as approximately 23,557 ha. Plantations are mainly distributed in the districts of Vinh Cuu, Xuan Loc, and Dinh Quan. As of writing this manuscript, very limited information is available on the classification of site indices for *Acacia* hybrid plantations in Dong Nai Province. The objectives of this study, therefore were; (i) to determine a baseline age of *Acacia* hybrid plantations to establish their site indices; and (ii) to develop site index curves for *Acacia* hybrid plantations in Dong Nai Province. Dong Nai Province was selected for the study site because many *Acacia* hybrid plantations have been planted in this area with different climatic conditions, topography and soil types. Currently, the total area of *Acacia* hybrid plantations in Dong Nai province is 23,000 ha (Institute for Forest Ecology and Environment 2017). The results of this study will provide the scientific basis for the application of silvicultural methods to effectively manage and use *Acacia* hybrid plantations.

MATERIALS AND METHODS

Description of the Study Site

This research was conducted on one to 10 year old *Acacia* hybrid (mention the hybrid type or parental species) plantations from in the districts of Vinh Cuu, Dinh Quan, Xuan Loc, Tan Phu, Long Thanh, and Bien Hoa in Dong Nai Province. These sites have three main soil types formed on basalt, shale and silt soil foundations in Dong Nai and all located between 10° 30' 03"- 11° 34' 57" in the northern latitudes and 106° 45' 30"- 107° 35' 00" in the eastern longitudes, near the equator at 50-350 m above sea level. The rainy season occurs in May to October, and the dry season occurs in November to April. The average temperature, rainfall, and humidity are 22 °C, 2100 mm, and 80%, respectively.

Experimental Design and Sample Collection

The site index (SI) for *Acacia* hybrid (*Acacia auriculiformis or Acacia mangium*) plantations was determined based on the dominant tree height (H_0) at a baseline age (A_0). Based on a preliminary survey of the age distribution of *Acacia* hybrid plantations in the study locations, standard sampling plots were established to measure growth criteria for each age group. Based on secondary data, three standard plots were established for each of the *Acacia* hybrid plantation age group, and each of those plots represented a typical kind of soil, as mentioned above. The areas of each standard plot varied due to plantation density at each study location; however, the number of trees per plot was consistently 39. Within each plot, three sample trees representing different growth status (Vietnam Standard 11567-1:2016, 2016) were cut for tree truncation; one tree of good growing status, one of medium growing status, and one of poor growing status. The remaining thirty-six trees were used to measure tree growth criteria. Thus, a total of 30 standard plots were established, in which 108 trees were measured to estimate the growth criteria and nine trees were used to measure truncation for each *Acacia* hybrid plantation age group. The truncated trees were not included in the estimation of tree growth criteria.

An average height (H_0) for each age group (from 1 to 10 years) was determined by the tree truncation method. The trees used for truncation were cut at 10 cm above the ground, and the diameter at breast height (DBH or D) and stem height (H_0) were determined before carrying out the tree truncation steps. Each trunk was cut into segments 1.0 m in length, except for the top trunk section, which was 0.5 m. Annual rings were counted at 0.0 m, 1.0 m, 1.3 m, 2.0 m, 3.0 m, 4.0 m and so on. At each truncated diameter of the tree, annual rings of the tree were counted to determine a tree age corresponding to the tree height reached within the truncated section. The rings within each tree were assembled and then labelled accrodingly for each truncated tree. The statistical characteristics described for H_0, such as the mean height (H_0), standard deviation (SD), coefficient of variation (CV), minimum height ($H_{0,\ min}$), maximum height ($H_{0,\ max}$) and difference of $H_{0,max}$ - $H_{0,min}$, were calculated by using results of statistical analyses.

Determination of a Site Index Function

The site index for *Acacia* hybrid plantations was constructed based on functions described by Schumacher (1939).

The observed empirical data of the 108 sample trees in each age group were used to fit the functions. The consistency of each fitted function (equation (3)) was evaluated by considering statistical factors, such as coefficient of determination (R^2), standard deviation (SD), mean absolute error (MAE) and mean absolute percent error (MAPE).

$H_0 = a*\exp(-b/A\hat{}c)$ (1)

or $Ln(H_0) = Ln(a) - b/A\hat{}c$ (2)

$Ln(H_0) = b_0 + b_1/A\hat{}c$ (3)

$H_0 = \exp(b_0 + b_1/A\hat{}c)$ (4)

$b_0 = Ln(H_0) - b_1/A\hat{}c$ (5)

where: $Ln(a) = b_0$ and $b = b_1$

From equations (4) and (5), a function of site index, SI = f (A), was defined by equation (6), and parameters of SI function, such as b_0, were defined by equation (7).

$Ln(SI) = b_0 + b_1/A_0\hat{}c$ (6)

$b_0 = Ln(SI) - b_1/A_0\hat{}c$ (7)

By substituting equation (7) into equation (3), equations (8-10) were obtained. Equation (10) is described as the function of site index, with H_0 at a certain baseline age (A_0).

$Ln(H_0) = Ln(SI) - b_1/A_0\hat{}c + b_1/A\hat{}c$ (8)

$Ln(SI) = Ln(H_0) - b_1/A_0\hat{}c + b_1/A\hat{}c$ (9)

$SI = \exp(Ln(H_0) - b_1(1/A\hat{}c - 1/A_0\hat{}c))$ (10)

Determination of A Baseline Age (A_0) and Parameters of Site Index Curve

An appropriate baseline age (A_0) was chosen at the time when SI was used to convert H_0 at A_0 to H_0 at a certain age (A) with the smallest regression sum of squares (SSR_{min}). The appropriate baseline age was tested for only *Acacia* hybrid plantations with age groups of 6-10 years (A = 6-10 years). The SI value was defined based on the fluctuation of H_0 at A_0 ($H_{0,max}$ - $H_{0,min}$). The slope (parameter b_1) remained the same across the site index functions. To obtain an SI curve, a value of b_1 from equation (4) was first calculated and then substituted into equation (10) along with the value of H_0 at A_0. The SI curves were validated by using empirical data measured from the truncated trees.

RESULTS AND DISCUSSION

Statistical Characteristics of *Acacia* Hybrid Plantation

The average H_0 values of the dominant trees varied from 2.6 m (year 1) to 22.4 m (year 10) (Table 1). The different ranges between $H_{0, min}$ and $H_{0, max}$ were from 2.1 to 3.3 m (year 1) and from 15.7 to 29.0 m (year 10). Coefficients of variation (CV) fluctuated from the highest 23.9% (year 2) to the lowest 14.7% (year 10). In general, H_0 values exhibited large variations with age and site conditions. Therefore, a categorization of *Acacia* hybrid plantations in Dong Nai Province into different site levels is necessary.

Selection of A Site Index Function

Based on the result of the regression and correlation analyses, the function $H_0 = f(A)$ that expresses a relationship between height and age of *Acacia* hybrid plantations for age groups from 1 to 10 years, was defined (Equation 11).

$$H_0 = \exp(3{,}65344 - 2{,}76734/A\text{^}0{,}70746) \quad (11)$$

with $r^2 = 83.4\%$; MAE = 2.2; MAPE = 16.2%.

H_0 values were fitted by substituting the values of age groups into equation 10 (Table 2). The annual periodic growth of height (ZH_0) increased gradually for the first year (2.4 m/year), reached a peak at 4.7 m/year in year 2, and then gradually decreased until age 10 (0.9 m/year). The annual average height growth (ΔH_0) also increased gradually starting at year 1 (2.4 m/year), reached the highest at year 3 (3.6 m/year), and then gradually decreased until age 10 (2.2 m/year). Height growth rate (Ph_0) decreased rapidly from 100% in year 1 to 14.1% in year 5 and decreased again to 4.1% in year 10. Thus, at age 2 the *Acacia* hybrid plantations transitioned from rapid to slow growth.

Table 1 Statistical characteristics of the tree heights in different age groups (n = 108)

A (year)	$H_{0, observed}$ (m)	CV (%)	$H_{0, min}$ (m)	$H_{0, max}$ (m)	$H_{0, max}$ - $H_{0, min}$ (m)
1	2.6	15.4	2.1	3.3	1.2
2	6.7	23.9	4.0	9.1	5.1
3	11.0	17.3	7.1	14.2	7.1
4	14.0	17.1	9.4	17.9	8.5
5	15.9	18.2	10.5	20.4	9.9
6	18.0	15.0	12.2	22.7	10.5
7	18.5	20.0	12.3	24.4	12.1
8	20.3	18.7	13.6	26.8	13.2
9	21.9	15.1	14.8	27.6	12.8
10	22.4	14.7	15.7	29.0	13.3

Notes: A = age; H_0 = height of dominant tree; CV = coefficient of variation; $H_{0, min}$ = minimum height; and $H_{0, max}$ = maximum height.

Table 2 Fitted values of periodic annual and average annual height growths and growth rate

A (year)	$H_{0\ fitted}$ (m)	ZH_0 (m/year)	ΔH_0 (m/year)	Ph_0 (%)
1	2.4	2.4	2.4	100.0
2	7.1	4.7	3.5	65.8
3	10.8	3.7	3.6	34.5
4	13.7	2.9	3.4	20.9
5	15.9	2.2	3.2	14.1
6	17.7	1.8	3.0	10.2
7	19.2	1.5	2.7	7.7
8	20.4	1.2	2.6	6.1
9	21.5	1.1	2.4	5.0
10	22.4	0.9	2.2	4.1

Notes: ZH_0 = periodic annual height growth; ΔH_0 = average annual height growth; and Ph_0 = height growth rate.

Figure 1 Periodic annual and average annual height growth of *Acacia* hybrid plantation by age

Baseline Ages (A_0) of *Acacia* Hybrid Plantations

Baseline ages (A_0) of the *Acacia* hybrid plantations were chosen at a year when the functions SI = f(A) were fitted with the smallest regression sum of squares (SSR_{min}). In this study, the ages of *Acacia* hybrid plantations ranged from 1 to 10 years; therefore, determination of an appropriate baseline age was tested at ages 6, 7, 8, 9 and 10 years. Predicted H_0 values based on equation (10) and differences between observed H_0 and predicted H_0 values are presented in Table 3. The highest and lowest values of SSR were 2.87 and 0.86 at the ages of 7 and 8, respectively. Thus, the appropriate baseline age used for constructing SI curves was 8 years. Age 8 is consistent with the mature age for *Acacia* hybrid plantations in southern Vietnam (Nguyen *et al.* 2006).

Table 3 Predicted H_0 at A_0 and SSR associated with H_0 for ages 6-10

A (year)	$H_{0,\,observed}$ (m)	Age (year)				
		6	7	8	9	10
		Predicted H_0 (m) at A_0 (year)				
6	18.0	18.0	19.5	20.8	21.9	22.8
7	18.5	17.1	18.5	19.7	20.7	21.6
8	20.3	17.6	19.1	20.3	21.4	22.3
9	21.9	18.0	19.5	20.8	21.9	22.8
10	22.4	17.7	19.2	20.4	21.5	22.4
		SSR values associated with the predicted H_0				
6		0.00	1.02	0.23	0.00	0.16
7		0.87	0.00	0.36	1.37	0.61
8		0.17	0.31	0.00	0.29	0.02
9		0.00	1.09	0.27	0.00	0.19
10		0.10	0.45	0.01	0.18	0.00
	Total sum of SSR:	1.14	2.87	0.86	1.84	0.98

Levels of Site Index at the Selected Baseline Age

The difference between $H_{0,\ max}$ and $H_{0,\ min}$ ($H_{0,\ max}$ - $H_{0,\ min}$ = 26.8 m - 13.6 m) at the selected baseline age of 8 is 13.2 m (rounded to 13.0 m) (Table 1). At the age of 8, the average height H_0 value for *Acacia* hybrid plantations was 20.4 m (rounded to 20.0 m). The measured error of height was usually from ±0.5 to ±1.0 m. If the H_0 value at the age of 8 (13.0 m) is divided into three levels, a range of each level is equal to 4.3 m (rounded to 4.0 m). The distance between two levels of adjacent site indices (4.0 m) is four to eight times higher than the measured error of height. Therefore, the *Acacia* hybrid plantation was divided into three levels of site indices (I, II, III) based on the H_0 values in which the distance between two levels of adjacent site indices was 4.0 m. The SI values of the three levels are; 24 m (Level I), 20 m (Level II) and 16 m (Level III) at the baseline age of 8. The SI values midway between levels I and II and midway between levels II and III were 22 m and 18 m, respectively. Similarly, the SI value at the lower margin of level III was 14 m, while the upper margin of level I was 26 m.

Selected Site Index Level Curves

In this study, the slope (b_1) of SI curves was the same for all three SI levels. The results of the regression analysis showed that the slope value (b_1) was 2.76734 and $1/A_0$^c was equal to 1/8^0.70746 = 0.22967. The values of these parameters were substituted into equation 9, and the SI curves were fitted (Table 4).

There were no significant differences in the growth intercepts between functions of SI = f (A) among the three site index levels and functions of H_0 = f (A), with p-values of 0.239, 0.285 and 0.261 for Levels I, II and III, respectively. Similarly, the slopes of the site index functions were not significantly different from those of the functions of H_0 (p-value = 0.570 for level I, p-value = 0.611 for level II and p-value = 0.380 for level III). These results proved that functions 11 to 17 can be used to construct site index curves for *Acacia* hybrid plantations as represented by the predicted values of site indices for each age group (Table 5) and the fitted site index curves of height values by years of *Acacia* hybrid plantations at levels of I_{upper}, I, I-II, II, II-III, III, and III_{lower} (Fig. 2).

Table 4 Functions of site index (SI) at selected levels.

SI levels	Fitted functions of SI	
I_{upper}	SI = exp (Ln (26) - 2.76734*(1/A^0.70746 – 0.22967))	(12)
I	SI = exp (Ln (24) - 2.76734*(1/A^0.70746 – 0.22967))	(13)
II - I	SI = exp (Ln (22) - 2.76734*(1/A^0.70746 – 0.22967))	(14)
II	SI = exp (Ln (20) - 2.76734*(1/A^0.70746 – 0.22967))	(15)
II - III	SI = exp (Ln (18) - 2.76734*(1/A^0.70746 – 0.22967))	(16)
III	SI = exp (Ln (16) - 2.76734*(1/A^0.70746 – 0.22967))	(17)
III_{lower}	SI = exp (Ln (14) - 2.76734*(1/A^0.70746 – 0.22967))	(18)

Table 5 Predicted values of site index levels for age groups from 1 to 10 years

A (year)	Predicted H_0 (m) at different site index levels						
	I_{upper}	I	I - II	II	II - III	III	III_{lower}
1	3.1	2.8	2.6	2.4	2.1	1.9	1.7
2	9.0	8.3	7.6	6.9	6.2	5.5	4.9
3	13.7	12.7	11.6	10.6	9.5	8.5	7.4
4	17.4	16.0	14.7	13.4	12.0	10.7	9.4
5	20.2	18.7	17.1	15.5	14.0	12.4	10.9
6	22.5	20.8	19.0	17.3	15.6	13.8	12.1
7	24.4	22.5	20.6	18.8	16.9	15.0	13.1
8	26.0	24.0	22.0	20.0	18.0	16.0	14.0
9	27.3	25.2	23.1	21.0	18.9	16.8	14.7
10	28.5	26.3	24.1	21.9	19.7	17.5	15.3

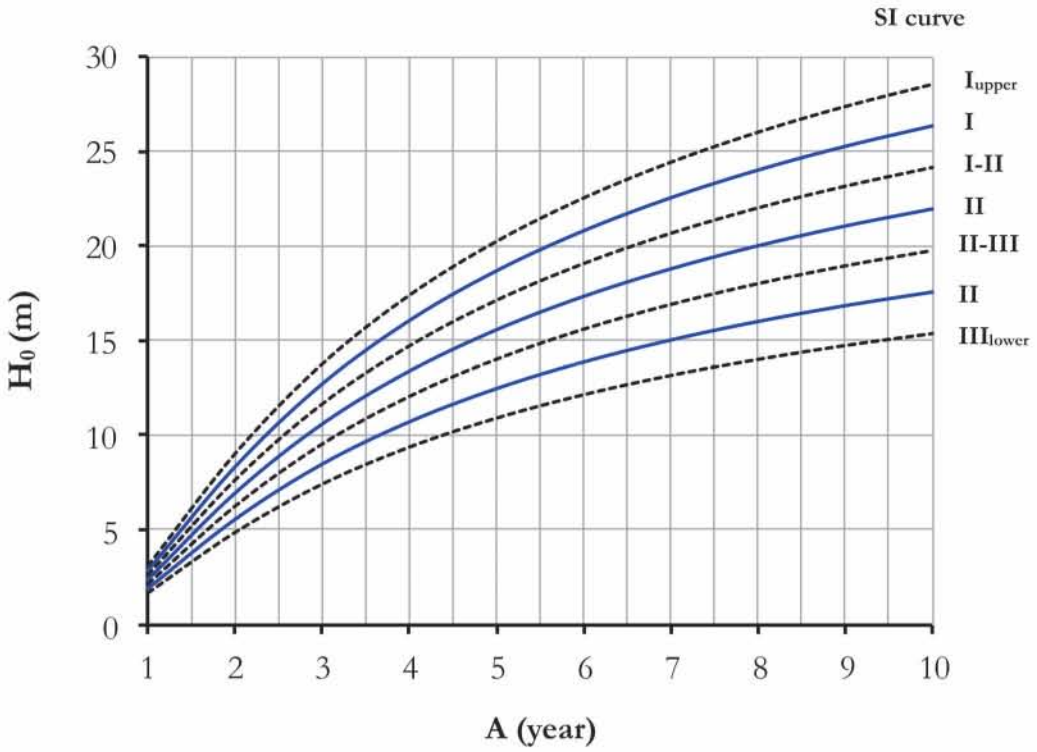

Figure 2 Curves of site indices associated with H_0 at different age groups

CONCLUSION

Acacia hybrid plantations in Dong Nai Province could be divided into three site index levels namely; Level 1 (24 m height), II (20 m) and III (16 m). For these three site index levels the appropriate baseline age of the plantations was at age 8. The site index curves for each level of the Acacia hybrid plantation sites were established according to the baseline age. Hence, to improve the efficiency of plantation industries, the owners need to focus on developing *Acacia* hybrid plantations with site index levels of I and II.

REFERENCES

Bao H. 2010. Study on methodologies for estimation of the carbon stock on natural forests as a basis for calculating CO_2 emissions from degradation and deforestation in Vietnam. Vietnamese Journal of Agriculture and Rural Development 1:1-10.

Bouman BAM, Plant RAJ, Nieuwenhuyse A. 1999. Quantifying economic and biophysical sustainability tradeoffs in tropical pastures. Journal of Ecological Model 120:31-46.

Brown S. 2002. Measuring carbon in forests: current status and future challenges. Journal of Environmental Pollution 116:363-72.

Chaiyo U, Garivait S, Wanthongchai K. 2011. Carbon storage in above-ground biomass of tropical deciduous forest in ratchaburi province, Thailand. World Academy of Science, Engineering and Technology 5(10):495-500.

Chambers JQ, Santos JS, Ribeiro RJ, Higuchi N. 2001. Tree damage, allometric relationships, and above-ground net primary production in central Amazon forest. Forest Ecology and Management 152:73-84.

Chavé J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, Folster H, Fromard F, Higuchi N, Kira T, Lescure JP, Nelson BW, Ogawa H, Puig H, Riéra B, Yamakura T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Ecosystem ecology, Oecologia 145:87-99.

Clutter JL, Fortson JC, Pienaar LV, Brister GH, Bailey RL. 1983. Timber management: A quantitative approach. New York (US): John Wiley & Sons, Inc. 333 p.

Dong SH. 1974. Volume curves of forest plants in Vietnam. Hanoi (VN): Forest Science Institute of Vietnam. 200 p.

FAO. 2009. Land. Assessment of the status of the development of the standards for the terrestrial essential climate variables. T9 FAO Report. Rome

(IT): Food and Agriculture Organization of the United Nations.

Institute for Forest Ecology and Environment. 2017. Results of forest inventory in Dong Nai province in 2016. Available at website: http://ifee.edu.vn/vi/news/du-an-trong-diem/ket-qua-kiem-ke-rung-tinh-dong-nai-nam-2016-64.html.

IPCC (Intergovernmental Panel on Climate Change). 2000. A Special Report of the IPCC. Land Use, Land- use Change, and Forestry. Cambridge (UK): Cambridge University Press.

Krisnawati H, Wang Y, Ades PK. 2010. Generalized height-diameter models for *Acacia mangium* Willd. plantations in South Sumatra. Indonesian Journal of Forestry Research 7(1):1-19.

Larsen DR. 1999. Site index, natural resource biometrics, construction of site index equations for *Pinus sylvestris* L. using permanent plot data in Sweden. Columbia (US): The School of Natural Resources, University of Missouri-Columbia.

Le DK. 2000. *Acacia* hybrid species and its soil improvement ability. *Vietnamese Journal of Forestry,* 6.

Lumbres RIC, Seo YO, Son YM, Doyog ND, Lee YJ. 2018. Height-age model and site index curves for *Acacia mangium* and *Eucalyptus pellita* in Indonesia. Forest Science and Technology 14(2): 91-6.

Monserud RA. 1984. Height growth and site index curves for inland Doughlas-fir based on stem analysis data and forest habitat type. Journal of Forest Science 30: 943–65.

Nguyen HS, Nguyen VT, Bui TH, Nguyen TM, Phan MS. 2006. Study on growth characteristics of *Acacia* hybrid plantations and its matured age in the Southern Vietnam. Vietnamese Journal of Forest Sciences 4.

Nguyen VL. 2012. Biomass estimation for calculating carbon stocks and CO_2 absorption in Yok Don National Park, Central Highlands, Vietnam, using remote sensing technology. Journal of Vietnam Environment 3:14-8.

Nguyen NL, Dao CK. 1999. Study on growth and productivity of plantations (*Pinus keysia* Royle ex Gordon) in Vietnam. Hanoi (VN): Vietnam Publishing House of Agriculture. 207 p.

Nguyen VT, Tran TN. 2016. Functions of biomass and adjusted coefficients for *Pinus keysiya* Royle ex Gordon on site index level I in Duc Trong District, Lam Dong Province. Vietnamese Science Journal of Agriculture and Forestry 2:57-65.

Nguyen VP, Tran QB, La NK. 2020. The economic and social efficiency of production *Acacia hybrid* plantations (*Acacia hybrid*) in Dong Nai Province. Vietnamese Journal of Forest Technology and Sciences 3:105-12.

Onyekwelu JC. 2003. Choosing appropriate index age for estimating site index of *Gmelina arborea* timber plantations in the Oluwa forest reserve. Journal of Food, Agriculture & Environment 1(3&4):286-90.

Vien NN. 2003. Study on biomass and primary productivity of *Avicennia alba* in Can Gio Biosphere, Ho Chi Minh City. Hanoi (VN): Forest Science Institute of Vietnam. 172 p.

Vietnam Standard (TCVN) 11567-1:2016. 2016. Lantation - Large timber plantation transformated from small wood - Part 1: *Acacia* hybrid (*A.mangium xA-auricculiformis*). Available at the website: http://luattrongtay.vn/ViewFullText/Id/664433ff-f408-4367-9258-05b2e0b146bd.

Vu TH. 2005. Forest productivity. Hanoi (VN): Vietnam Publishing House of Agriculture.

Vu TH. 2012. Volume chart of standing trees. Hanoi (VN): Vietnam Publishing House of Agriculture. 212 p.

Vu TP, V DH. 2011. Biomass structure of pine plantations in Lam Dong Province. Vietnamese Joural of Forest Science 2:1813-27.

Zianis D, Muukkonen P, Makipaa R, Mencuccini M. 2005. Biomass and stem volume equations for tree species in Europe. Monographs 4. 63 p.