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

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ABSTRACT

This article introduces the research results of a site index classification for *Acacia* hybrid plantations in Dong Nai Province. The objectives of this study were to (i) determine a baseline age of *Acacia* hybrid plantations to establish their site indices and (ii) 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; 108 trees were measured for the estimation of growth criteria. Three trees were used for tree truncation, and truncated trees did not count for the estimation of tree growth criteria. In this study, the site index (SI) for *Acacia* hybrid plantations was divided into three levels according to the total height of the dominant trees. The heights collected from 108 trees were used to build the functions of the SI, and three truncated trees were used to examine the possibilities of the functions of SI. Research results showed that the appropriate baseline age of *Acacia* hybrid plantations at Dong Nai Province is 8 years. The site indices of hybrid plantations were divided into three site levels of I, II, and III, corresponding to heights of 24, 20 and 16 m, respectively. To improve the effectiveness of *Acacia* hybrid plantation businesses, owners should focus on growing plantations at site index levels of I or II.

Keywords: *Acacia* hybrid plantations; dominant trees; site index; curve of 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 important role in balancing the global carbon cycle and CO_2 concentration on Earth (Chaiyo *et al*., 2011). Research on forest biomass and carbon sequestration is significant for forest management and planning, as well as biomass energy use (Brown, 2000 & 2002; Zianis *et al.*, 2005). According to the FAO (2009), biomass changes are associated with increases in forest ecosystem growth and rates of carbon absorption and emission. A ratio of biomass to carbon intensity for a forest population depends on an age and site index (Nguyen and Tran, 2016). Chavé *et al.* (2005) indicated that an accurate estimation of forest biomass is an important factor in assessing the global carbon cycle.

Bouman *et al.* (1999) 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 forest biomass and carbon stocks (Chambers *et al.*, 2001; Brown,

2002, Chavé et al., 2005). Several previous studies developed mathematic models for the estimation of forest productivity (Dong, 1974; Nguyen and Dao, 1999; Vu, 2005 & 2012) and biomass functions (Vien, 2008: Bao, 2010; Vu and Vo, 2011; Nguyen, 2012; Dang, 2014; Nguyen and Tran, 2016) for timber trees and different types of natural forests. According to the best understanding of the authors, there are few studies on site index curves of *Acacia mangium* Willd (Krisnawati *et al*., 2010; Lumbres *et al*., 2018); however, there are no published studies on biomass estimation of *Acacia* hybrid plantations with various tree ages and soil site indices. Therefore, it is essential to predict *Acacia* hybrid plantation biomasses to determine functions based on different site indices.

According to Nguyen and Dao (1999), forest soil site index or soil productivity is a criterion for evaluation of site suitability for forest productivity. Quality of a soil site (productivity of a soil site) reflects the productivity capacity of a forest, which might change due to effects of over-exploitation, fire, fertilizer provision and/or soil erosion (Clutter *et al*., 1983). Site quality can be 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 value depends on tree species and can be 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, with 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 from statistical tests (Larsen, 1999; Vu, 2005 & 2012).

Some researchers have studied the planting and breeding of *Acacia* hybrid species in Vietnam (Le, 2000). Nguyen *et al.* (2006) showed that the mature age of *Acacia* hybrid plantations in southern Vietnam is eight years. According to 2016 statistics, the total area of *Acacia* hybrid plantations in Dong Nai Province is approximately 23,557 ha. Plantations are mainly distributed in the districts of

Vinh Cuu, Xuan Loc, and Dinh Quan. So far, there are no studies on the classification of site indices for *Acacia* hybrid plantations in Dong Nai Province. The objectives of this study 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. We selected the Dong Nai province for the site study 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 provide the scientific basis for the application of silvicultural methods to manage and use *Acacia* hybrid plantations effectively.

MATERIALS AND METHODS

Description of the study site

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

Experimental design and sample collection

In this study, the site index (SI) for *Acacia* hybrid (*Acacia auriculiformis*Acacia mangium*) plantations was dependent 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 *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), including one tree of good growing status, one of medium growing status, and one of poor growing status, were cut for tree truncation. 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 for the estimation of growth criteria and nine trees were used for tree truncation for each *Acacia* hybrid plantation age group. The truncated trees did not count toward the estimation of tree growth criteria.

An average height (H_0) for each age group (from 1 to 10 years) was determined by the method of tree truncation. The trees used for truncation were cut down at a position of 10 cm above the ground, and information was collected on diameter at breast height (DBH or D) and body height (H_0) before carrying out the steps of tree truncation. 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 that corresponded to the height of the tree reached within the truncated section. The rings within each tree were assembled and then named in order for each truncated tree. The statistical characteristics described for H_0, such as the mean value of height (H_0), standard deviation (SD), coefficient of variation (CV), smallest value of height ($H_{0,\ min}$), maximum value of height ($H_{0,\ max}$) and difference of $H_{0,max}$ - $H_{0,min}$, were calculated through statistical analyses.

Determination of a site index function

Functions described by Schumacher (1939) were applied to construct a site index for *Acacia* hybrid plantations, as presented in equations below. The observed, empirical data of 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).

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

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

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

$H_0 = \exp(b_0 + b_1/A\text{^}c)$ (3')

$b_0 = Ln(H_0) – b_1/A\text{^}c$ (4)

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

From equations (3) and (4), a function of site index (SI = f (A)) was defined by equation (5), and parameters of SI function, such as b_0, were defined by equation (6).

$Ln(SI) = b_0 + b_1/A_0\text{^}c$ (5)

$b_0 = Ln(SI) – b_1/A_0\text{^}c$ (6)

By substituting equation (6) into equation (3'), we obtained equations (7-9). Equation (9) is described as the function of site index, with H_0 at a certain baseline age (A_0).

$Ln(H_0) = Ln(SI) – b_1/A_0\text{^}c + b_1/A\text{^}c$ (7)

$Ln(SI) = Ln(H_0) – b_1/A_0\text{^}c + b_1/A\text{^}c$ (8)

$$SI = \exp(\mathrm{Ln}(H_0) - b_1(1/A^{c} - 1/A_0^{c})) \quad (9)$$

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 number of SI 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 (3) was first calculated and then substituted into equation (9) 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 statistical characteristics of the height of dominant trees for age groups (1-10 years) are presented in Table 1.

Table 1. Statistical characteristics of the height of trees 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

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

The results in Table 1 show that the average H_0 values of dominant trees varied from 2.6 m at year 1 to 22.4 m in year 10. The ranges of the difference between $H_{0,\ min}$ and $H_{0,\ max}$ were from 2.1 to 3.3 m for year 1 and from 15.7 to 29.0 m for year 10. Coefficients of variation (CV) fluctuated from the highest value (23.9%) in year 2 to the lowest value (14.7%) in year 10. In general, H_0 values

exhibited large variations with age and site conditions. Therefore, a division 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, a 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, as shown in equation (10).

$H_0 = \exp(3{,}65344 - 2{,}76734/A\text{^}0{,}70746)$ (10)

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

Table 2 shows H_0 values that were fitted by substituting the values of age groups into equation (10). 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 in year 1 (2.4 m/year), reached the highest value 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, age 2 is the period that the *Acacia* hybrid plantations transition from rapid to slow growth.

Table 2. Fitted values of annual periodic and average growths and height 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

Where ZH_0 = annual periodic growth of height, ΔH_0 = annual average growth of height, and Ph_0 = height growth rate.

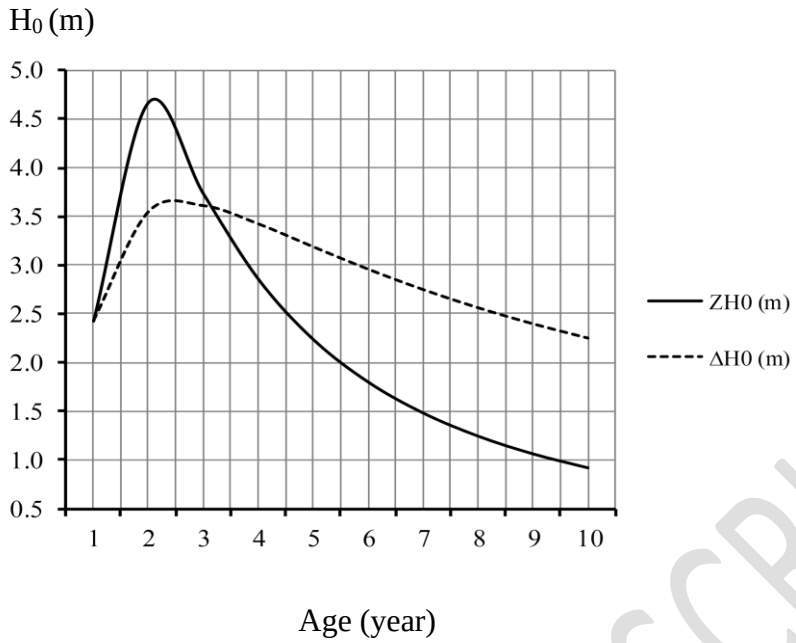

Figure 1. Annual periodic and average height growth of *Acacia* hybrid plantation by age

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 of 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 the ages of 6, 7, 8, 9 and 10. 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

As presented in Table 1, 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). At the age of 8, the average 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 values of three SI levels (24, 20 and 16 m) at the baseline age of 8 corresponded to site indices of I, II, and III, respectively. 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 value for all three SI levels. The results of the regression analysis showed that the value of slope (b_1) was 2.76734 and $1/A_0$^c was equal to 1/8^0.70746 = 0.22967. We substituted the values of the above parameters into equation 9, and the SI curves are presented in Table 4.

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))	(11)
I	SI = exp(Ln(24) - 2.76734*(1/A^0.70746 – 0.22967))	(12)
II - I	SI = exp(Ln(22) - 2.76734*(1/A^0.70746 – 0.22967))	(13)
II	SI = exp(Ln(20) - 2.76734*(1/A^0.70746 – 0.22967))	(14)
II - III	SI = exp(Ln(18) - 2.76734*(1/A^0.70746 – 0.22967))	(15)
III	SI = exp(Ln(16) - 2.76734*(1/A^0.70746 – 0.22967))	(16)

III_{lower}	SI = exp(Ln(14) - 2.76734*(1/A^0.70746 – 0.22967))	(17)

There were no significant differences in growth intercepts between functions of SI = f (A) at three site index levels and functions of H_0 = f (A), with p-values of 0.239, 0.285 and 0.261 for the I, II and III levels, 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 prove that functions 11 to 17 can be used to construct site index curves for *Acacia* hybrid plantations. Predicted values of site indices for each age group are presented in Table 5. Figure 2 described 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}.

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

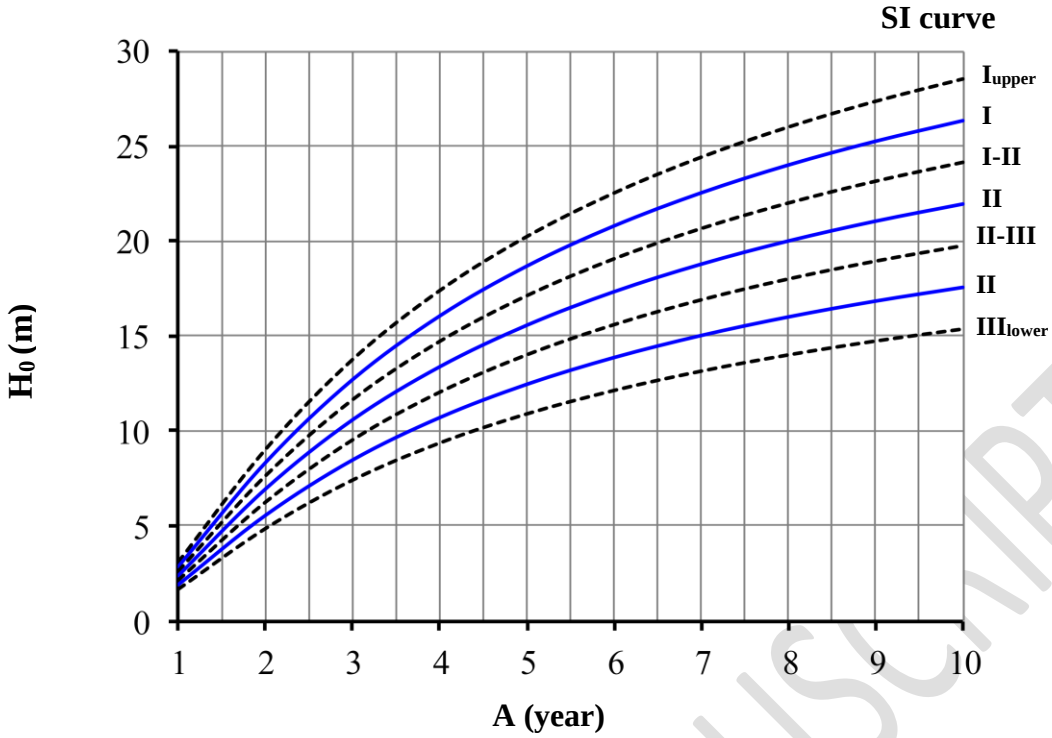

Figure 2. Curves of site indices associated with H_0 at different age groups.

CONCLUSION

Acacia hybrid plantations in Dong Nai Province could be divided into three site index levels. The appropriate baseline ages of these plantations were determined to be age 8 for three site index levels. The site index level curves for the Acacia hybrid plantation sites were established according to the baseline age. To improve the efficiency of plantation businesses, owners should focus on *Acacia* hybrid plantations with site index levels of I and II.

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