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MỤC LỤC

Trang

STUMP DIAMETER CHARACTERISTICS AND VOLUME PREDICTION FOR *Acacia mangium* IN BA VI, VIETNAM

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SUMMARY
Tree stump diameter plays a big role in forest resource management. The study used data from 23 plots. The results showed that the acacia community was classified into 2 clusters. The stump diameter mean of cluster 1 is larger than cluster 2. The stump diameter frequency distribution of cluster 1 was more right-skewed. The research tested five theoretical distributions including: Normal, Lognormal, Weibull, SHASH, Johnson. Analyzed results indicated that the Weibull distribution was the best for modeling the stump diameter frequency distribution. The correlation between the base diameter and the diameter at breast height, total height, and tree volume was best described by the Power function. Between the stump diameter and the diameter at breast height, the parameters of the Power equation for cluster 1 were 0.669 and 1.056. Meanwhile, these parameters of cluster 2 were 0.708 and 1.041. However, the Cubic equation was the best for describing the regression between the base diameter and the total height of cluster 2. The Power function has also been used to build 2 volume prediction tables for 2 clusters. These tables will help forest rangers in Ba Vi and other areas with similar conditions to tracing the volume of lost trees, contributing to sustainable and effective forest management.
Keywords: ***Acacia magium*, Ba Vi, multivariate analysis, stump diameter, volume table.**

1. INTRODUCTION

Currently, forest resources are being seriously degraded in many parts of Vietnam. Illegal logging activities have also been taking place in many provinces (Pham Binh Quyen, 1998). The government and forest rangers have made many efforts to limit and prevent these activities. After being exploited, the forest trees are left with only the stump. The information about the diameter and height of the stumps is very significant information. They can be used for different purposes such as estimating the tree volume has been lost, estimating the total volume to be harvested or thinned, estimating damages of natural disasters etc (Ramazan Özçelík et al., 2010; Elias Milios et al., 2016).

In tree measurement field, diameter at breast height and total height are the most concerned variables. Because, the diameter at breast height and total height are often used to estimate the volume of forest trees, calculate the biomass and carbon stocks of forest trees and stands (Kenneth L Quigley, 1954; Elias Milios et al., 2016). Therefore, finding out the relationship between the stump diameter and the diameter at breast height and the total height will be very meaningful for forest resources management.

In Vietnam, studies on the stump diameter characteristics are very limited. There were some studies conducted in the 2000s studied the base diameter of *Vatica odorata* species in Nghe An and Yen Bai provinces (Dinh Hong Khanh, 2000), acacia and pine in Xuan Mai, Chuong My, Hanoi (Tran Dang Nam, 1999; Tran Trong Nghia, 1999). For a long time after that, the determination of the volume of lost trees has not been interested in both theory and practice in Vietnam. However, in the face of ongoing illegal logging, serious consequences of wind storms, landslides and other natural disasters, so it is essential to predict the tree volume from the base diameter. It means a lot to the forest management in Vietnam.

Acacia is a key species for plantations and accounts for a large proportion in the programs of planting and restoring forests in many ecological regions throughout the country (Nguyen Hoang Nghia, 2007). Therefore, in the years 1995-2000, the Moncada station under the Vietnam ruminant breeding center planted an area of more than 40 hectares of Acacia forest, mostly *Acacia mangium* with good seeding quality. After more than 20 years of tending and management, the Acacia forest here has grown and developed well. However, there has not been any study on the characteristics of the stump diameter and the relationship between it and the diameter at breast height, the total height and the tree volume has been conducted here. Therefore, this study was conducted with the aim to: 1) analyze the stump diameter characteristics of *Acacia mangium* in the study area and 2) build volume tables to predict the volume of acacia trees from the base diameter in order to support for effective and sustainable forest management in there and other areas with similar conditions.

2. RESEARCH METHODOLOGY

2.1. Data collection methods

The study has conducted to establish 23 plots on an area of more than 40 hectares of *Acacia mangium* forests in Moncada company, Ba Vi, Vietnam. The area of each plot was 500 m^2 (20 m x 25 m). The sampling method was a stratified random method. This method is suitable when the forest is not homogeneous (Barry D. Shiver et al., 1996). Locations of the plots were shown in the figure below.

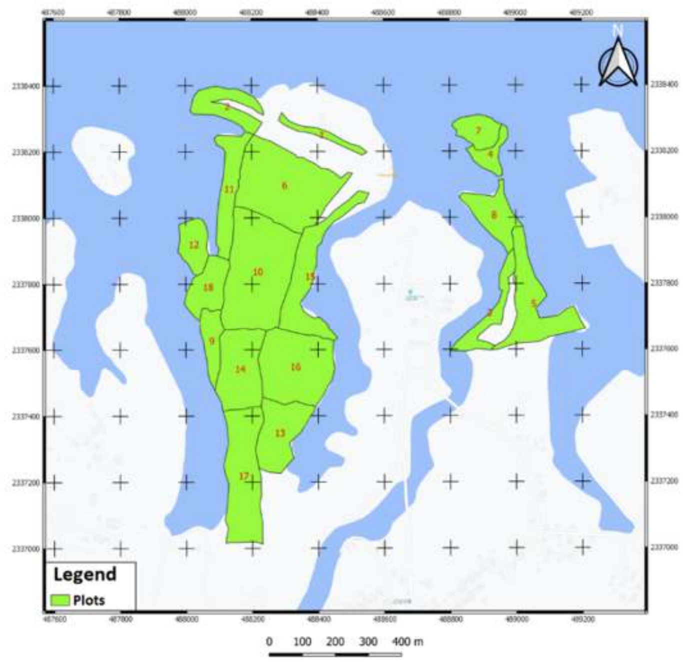


Figure 1. Plot arrangement

After establishing the plots, the acacia trees were measured. The study measured all trees with diameters greater than or equal to 3 cm. On each tree, the stump diameter (20 cm above the ground) (Do), diameter at breast height (DBH or D1.3), total height (H), commercial height (C_H), crown width (Dc) and growth quality were measured and evaluated.

2.2. Data analysis methods

2.2.1. Community classification analysis

The K-mean distance cluster method was used to group plots based on multiple growth variables such as: the stump diameter, diameter at breast height, total height, commercial height and crown width. Clustering methods are based on a matrix of variable values. These methods are suitable for classifying communities into more homogeneous groups (Bruce McCune et al., 2002).

2.2.2. The stump diameter characteristics analysis

Descriptive statistics were computed to provide information about the stump diameter datasets. The used descriptive statistics were count, minimum, maximum, mean, standard deviation, skewness and kurtosis (Jerrold H. Zar, 2010).

Frequency distributions between the two clusters was compared using Permutational multivariate analysis of variance (Permanova). This is a nonlinear method, so it does not require assumptions (Kathy Mier, 2012; Andreas Hamann, 2016).

Five probability distributions were tested to find the best one to simulate the base diameter frequency distribution, including: Normal, Lognormal, Weibull, Exponential, SHASH and Johnson. The best distribution will be found based on the AIC value. The distribution with the smallest AIC value will be the best distribution.

The AIC formula for The Least Squares Case is calculated by following formula (Kenneth P. Burnham et al., 2002).

$$AIC = n * \ln(RSS/n) + 2 * K$$

Where,

n is the number of observations;

RSS is the Residual Sum of Square;

K is the number of parameters in the model.

Principal component analysis was used to analyze the relationship between the stump diameter and the remaining variables including diameter at breast height, total height, commercial height and crown width. This is a multivariate analysis method based on the matrix values of the variables averaged for each plot (Bruce McCune et al., 2002).

2.2.3. Regression analysis between variables

Correlation analysis between the base diameter with diameter at breast height, total height and tree volume used 10 models as follows (Robert Ho, 2013).

- Linear: $Y=b_1+b_2*X$
- Logarithmic: $Y= b_1+(b_2*\ln(X))$
- Inverse: $Y=b_1+(b_2/X)$
- Quadratic: $Y= b_1+(b_2*X)+(b_3*X\text{^}2)$
- Cubic: $Y= b_1+(b_2*X)+(b_3*X\text{^}2) +(b_4*X\text{^}3)$
- Power: $Y= b_1*(X\text{^}b_2)$
- Compound: $Y= b_1*(b_2\text{^}X)$
- S: $Y= e\text{^}(b_1+(b_2/X))$
- Growth: $Y=e\text{^}(b_1+(b_2*X))$
- Exponential: $Y=b_1*(e\text{^}(b_2*X))$.

The best model was the one with the largest adjusted R-squared value (Jerrold H. Zar, 2010).

All calculations were performed by Spss 26.0 and R 3.6.2 software.

2.2.4. Volume prediction table building

Because the study was not allowed to cut down trees, so the volume of forest trees was calculated according to the following formula (Bui Manh Hung, 2016):

$V_i=G_i*H_i*f$

In which: V_i is the volume of tree I;

G_i is the basal area of tree I;

H_i is the total height of tree I;

f is tree form. f = 0.5, because this is a plantation.

Then, based on the best correlation function between the stump diameter and tree volume to build up volume prediction tables for the study area.

3. RESULT

3.1. Community classification

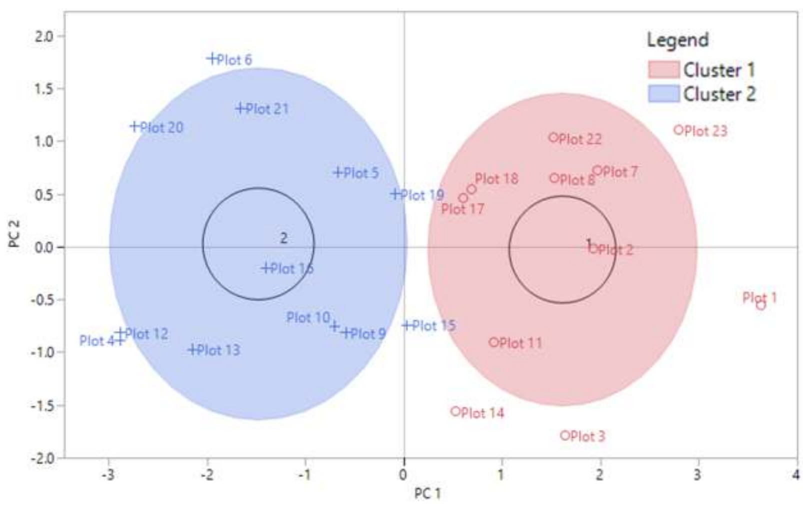


Figure 1. Community classification with 95% confidence estimation

From the data collected from 23 plots set up in the study area. The classification results based on the tree stump diameter showed that there were 2 clear different clusters. Cluster 1 included 12 plots, and cluster 2 consisted of 11 plots. Thus, the Acacia community can be divided into two groups. Survey data in each group can be aggregated for further analyses.

3.2. Base diaemeter characteristics

3.2.1. Descriptive characteristics

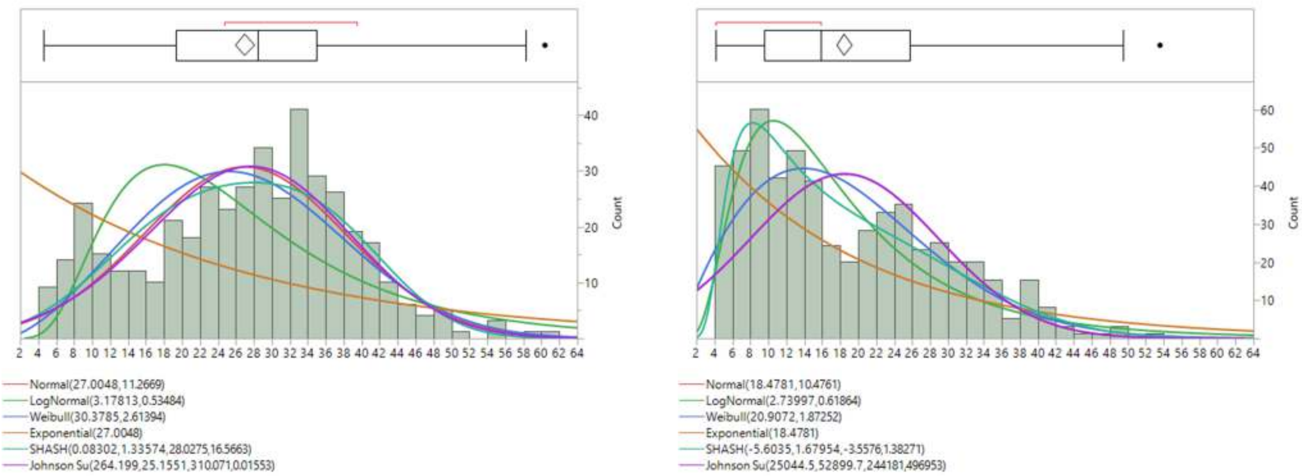
Descriptive statistics were calculated for each cluster and were presented in the table below.

Table 1. Descriptive characteristics of the base diamater

	N	Minimum	Maximum	Mean	Variance	Skewness	Kurtosis
Cluster 1	434	4.6	60.4	27.005	11.2669	-0.088	-0.485
Cluster 2	566	4.1	53.6	18.478	10.4761	0.640	-0.405

Descriptive values indicated that the number of individuals of cluster 1 was lower than that of cluster 2 by 132. Both the smallest and the largest values of cluster 1 were greater than that of cluster 2. The mean value of cluster 1 was also larger than cluster 2 by approximately 9 cm. The frequency distribution of cluster 1 was right-skewed, while that of cluster 2 was left-skewed.

3.2.2. Frequency distribution and modelling comparison



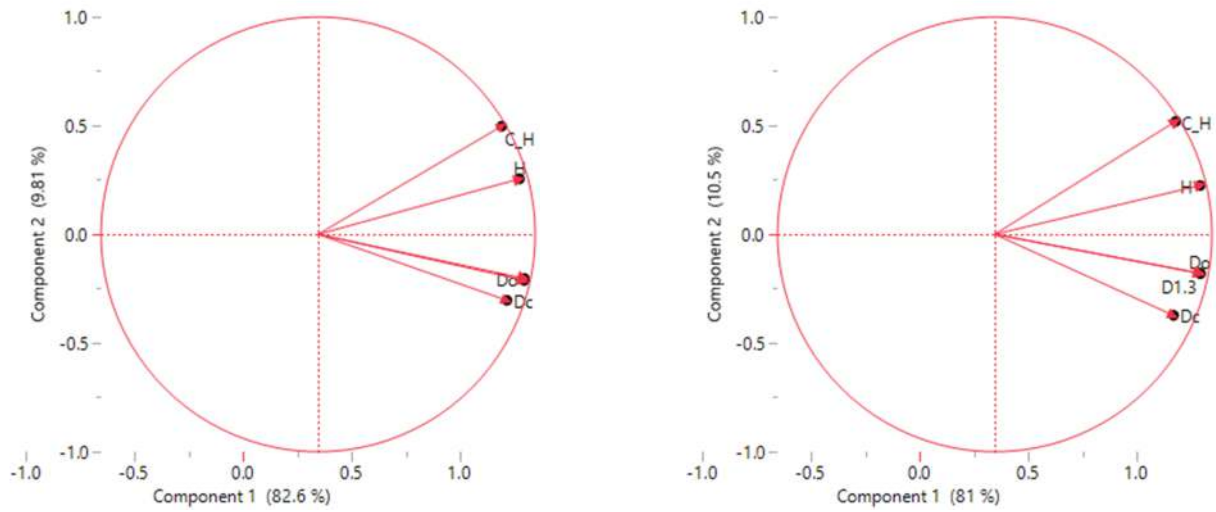
a) **b)**

Figure 2. The base diameter frequency distribution and modelling.
Green bars showed the number of trees in each group. Curved solid lines were analyzed theoretical distributions. a) for cluster 1 and b) for cluster 2.

The base diameter frequency distribution of cluster 1 tended to be skewed to the right, with the largest number of trees concentrated in groups from 22 cm to 38 cm. Meanwhile, groups with a large number of individuals in cluster 2 was concentrated from 4 cm to 16 cm, then tended to decrease as the base diameter increased. The base diameter frequency distributions were significantly different between two clusters (Permanova, p value < 0.0001).

In 6 analyzed distributions, Weibull was the best distribution for both clusters (AIC = 3331.18 for cluster 1, AIC = 4163.74 for cluster 2). At the same time, the good of fit test also showed that the data was from the Weibull distribution in both clusters (Kolmogorov test, p = 0.01). However, the parameters were different between clusters. For cluster 1, the scale and shape parameters of the found Weibull distribution were 30.37 and 2.61, respectively. Meanwhile, these parameters for cluster 2 were 20.90 and 1.87, respectively.

3.2.3. Relations with other variables



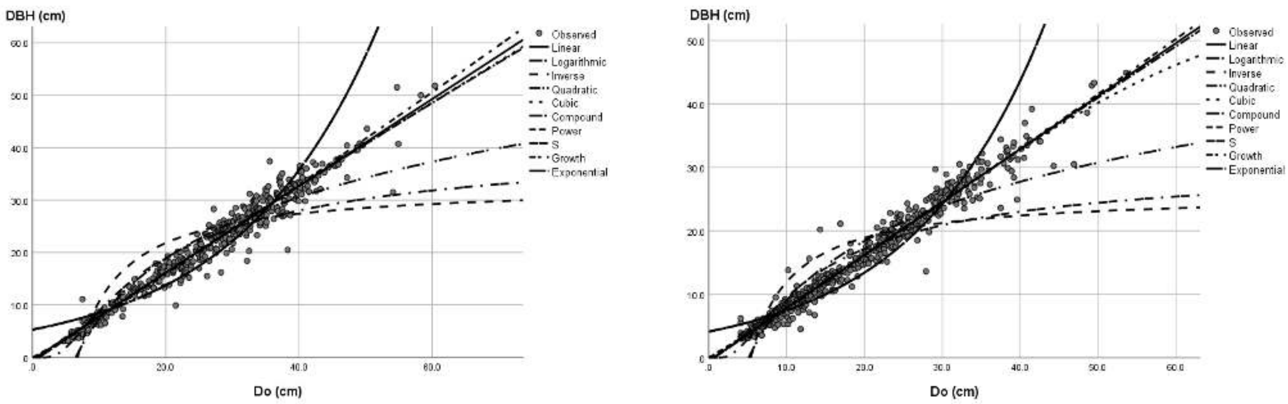
a) b)

Figure 3. Principal component analysis for the base diameter (Do), diameter at breast height (D1.3), total height (H), commercial height (C_H), crown width diameter (Dc). a) for cluster 1 and b) for cluster 2.

Principal component analysis illustrated that the stump diameter had the strongest and most co-trending relationship with diameter at breast height, then crown width diameter, total height and finally commercial height. However, this relationship was a little stronger in cluster 1, especially between the base diameter and the diameter at breast height in cluster 1.

3.2.4. Regression equations with diameter at breast height and total height

a. The base diameter and the diameter at breast height

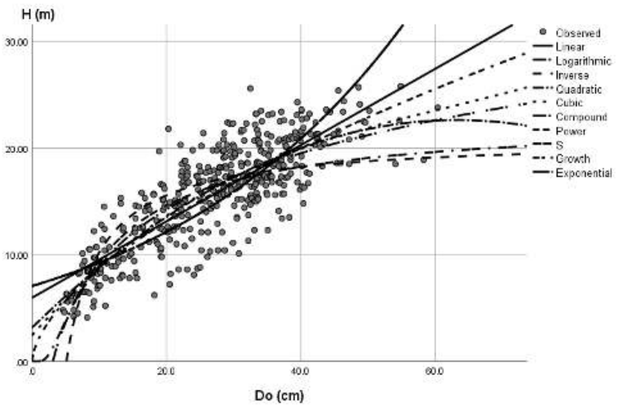


a) b)

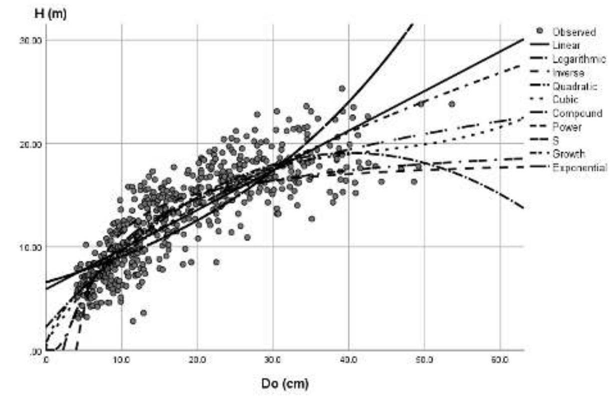
Figure 4. Regression analysis charts for the base diameter (Do) and diameter at breast height (DBH). a) for cluster 1 and b) for cluster 2.

Among tested equations for the analysis, the Power function was the best one to simulate the relationship between the base diameter and the dbh in both clusters (R square was 0.965 and 0.968 respectively). All models existed in the population (Nonlinear regression, $p < 0.0001$). The parameters of the Power equation for cluster 1 were 0.669 and 1.056. Meanwhile, these parameters of cluster 2 were 0.708 and 1.041.

b. The base diameter and the total height



a)



b)

Figure 5. Regression analysis charts for the base diameter (Do) and the total height. a) for cluster 1 and b) for cluster 2.

The relationship between the stump diameter and the total height was also explored using 10 different types of functions. In which, the power function was the best function for cluster 1 (R square = 0.729) and the cubic function was the best function for cluster 2 (R square = 0.765). All models also existed in the population (Nonlinear regression, $p < 0.0001$). The parameters of the Power equation for cluster 1 were 2.144 and 0.605. Parameters of the Cubic function for cluster 2 were 0.749, 1.110, -0.024 and 0.000183.

3.3. Volume prediction based on the stump diameter

The correlation between the stump diameter and the tree volume was also tested using 10 different types of functions. The results showed that the power function was a very excellent function to describe the relationship between these two variables in both clusters (R square was 0.955 and 0.954, respectively). The parameters of the power function used to predict the tree volume for cluster 1 were 0.000004 and 2.718. Meanwhile, these parameters of cluster 2 were 0.000005 and 2.679.

Table 2. Predicted tree volume for cluster 1

Limits	Middle value	Volume	Limits	Middle value	Volume	Limits	Middle value	Volume
3 - 4	3.5	0.00011	26 - 27	26.5	0.02783	49 - 50	49.5	0.15208
4 - 5	4.5	0.00022	27 - 28	27.5	0.03078	50 - 51	50.5	0.16058
5 - 6	5.5	0.00039	28 - 29	28.5	0.03392	51 - 52	51.5	0.16937
6 - 7	6.5	0.00061	29 - 30	29.5	0.03725	52 - 53	52.5	0.17846
7 - 8	7.5	0.00090	30 - 31	30.5	0.04079	53 - 54	53.5	0.18785
8 - 9	8.5	0.00127	31 - 32	31.5	0.04452	54 - 55	54.5	0.19755
9 - 10	9.5	0.00171	32 - 33	32.5	0.04847	55 - 56	55.5	0.20755
10 - 11	10.5	0.00225	33 - 34	33.5	0.05263	56 - 57	56.5	0.21787
11 - 12	11.5	0.00288	34 - 35	34.5	0.05701	57 - 58	57.5	0.22852
12 - 13	12.5	0.00361	35 - 36	35.5	0.06162	58 - 59	58.5	0.23948
13 - 14	13.5	0.00445	36 - 37	36.5	0.06645	59 - 60	59.5	0.25077
14 - 15	14.5	0.00541	37 - 38	37.5	0.07151	60 - 61	60.5	0.26239
15 - 16	15.5	0.00648	38 - 39	38.5	0.07682	61 - 62	61.5	0.27434
16 - 17	16.5	0.00768	39 - 40	39.5	0.08236	62 - 63	62.5	0.28664
17 - 18	17.5	0.00901	40 - 41	40.5	0.08815	63 - 64	63.5	0.29927
18 - 19	18.5	0.01048	41 - 42	41.5	0.09419	64 - 65	64.5	0.31226

Limits	Middle value	Volume	Limits	Middle value	Volume	Limits	Middle value	Volume
19 - 20	19.5	0.01209	42 - 43	42.5	0.10049	65 - 66	65.5	0.32559
20 - 21	20.5	0.01385	43 - 44	43.5	0.10705	66 - 67	66.5	0.33928
21 - 22	21.5	0.01577	44 - 45	44.5	0.11387	67 - 68	67.5	0.35333
22 - 23	22.5	0.01784	45 - 46	45.5	0.12096	68 - 69	68.5	0.36773
23 - 24	23.5	0.02008	46 - 47	46.5	0.12832	69 - 70	69.5	0.38251
24 - 25	24.5	0.02249	47 - 48	47.5	0.13596			
25 - 26	25.5	0.02507	48 - 49	48.5	0.14388			

Table 3. Predicted tree volume for cluster 2

Limits	Middle value	Volume	Limits	Middle value	Volume	Limits	Middle value	Volume
3 - 4	3.5	0.00013	26 - 27	26.5	0.02976	49 - 50	49.5	0.15877
4 - 5	4.5	0.00026	27 - 28	27.5	0.03287	50 - 51	50.5	0.16751
5 - 6	5.5	0.00044	28 - 29	28.5	0.03617	51 - 52	51.5	0.17655
6 - 7	6.5	0.00069	29 - 30	29.5	0.03967	52 - 53	52.5	0.18588
7 - 8	7.5	0.00101	30 - 31	30.5	0.04338	53 - 54	53.5	0.19552
8 - 9	8.5	0.00141	31 - 32	31.5	0.04730	54 - 55	54.5	0.20547
9 - 10	9.5	0.00191	32 - 33	32.5	0.05143	55 - 56	55.5	0.21572
10 - 11	10.5	0.00249	33 - 34	33.5	0.05578	56 - 57	56.5	0.22630
11 - 12	11.5	0.00318	34 - 35	34.5	0.06035	57 - 58	57.5	0.23719
12 - 13	12.5	0.00397	35 - 36	35.5	0.06515	58 - 59	58.5	0.24840
13 - 14	13.5	0.00489	36 - 37	36.5	0.07019	59 - 60	59.5	0.25994
14 - 15	14.5	0.00592	37 - 38	37.5	0.07546	60 - 61	60.5	0.27181
15 - 16	15.5	0.00707	38 - 39	38.5	0.08097	61 - 62	61.5	0.28402
16 - 17	16.5	0.00836	39 - 40	39.5	0.08673	62 - 63	62.5	0.29656
17 - 18	17.5	0.00979	40 - 41	40.5	0.09274	63 - 64	63.5	0.30945
18 - 19	18.5	0.01136	41 - 42	41.5	0.09900	64 - 65	64.5	0.32268
19 - 20	19.5	0.01308	42 - 43	42.5	0.10552	65 - 66	65.5	0.33626
20 - 21	20.5	0.01496	43 - 44	43.5	0.11231	66 - 67	66.5	0.35019
21 - 22	21.5	0.01700	44 - 45	44.5	0.11936	67 - 68	67.5	0.36448
22 - 23	22.5	0.01920	45 - 46	45.5	0.12668	68 - 69	68.5	0.37913
23 - 24	23.5	0.02157	46 - 47	46.5	0.13428	69 - 70	69.5	0.39414
24 - 25	24.5	0.02412	47 - 48	47.5	0.14216			
25 - 26	25.5	0.02685	48 - 49	48.5	0.15032			

The results of tree volume prediction for the base diameter classes for the two clusters were shown in Tables 2 and 3. Each class contained lower limits, upper limites, middle values and the corresponding tree volume in each class. The groups run from 3 cm to 70 cm.

4. DISCUSSION

4.1. The stump diameter characteristics

The stump diameter is a problem that has received little attention in the past in Vietnam, because it is often influenced by the root system and is more difficult to measure in the forest. However, at present, illegal logging is happening very complicatedly in many localities, so the stump is the only thing left behind after logging in the forest. Therefore, this is an important basis for determining the growth indices and the lost plant volume

(Kenneth L Quigley, 1954; Elias Milios et al., 2016).

The analyzed results showed that the stump diameter mean of cluster 1 was bigger than cluster 2 and the distribution has a left-skewed shape. This can be explained by selective logging of some large trees in the past and there are more big trees with disease, broken down in cluster 2. After cutting or the tree falling will create huge gaps in the forest. These gaps will be a favorable environment for natural regeneration to grow and develop (Jiaojun Zhu et al., 2014). Therefore, the number of regenerating and smaller diameter trees is much more in cluster 1. Therefore, this has resulted in a smaller mean and a left-shifted peak of the frequency distribution. These findings are completely similar to the results of a research conducted in China (Li-feng Zheng et al., 2010).

The Normal, Lognormal, Weibull, Exponential, SHASH and Johnson distributions are commonly used functions to model the diameter and height frequency distribution (Teresa Fidalgo Fonseca et al., 2009; Mehrdad Mirzaei et al., 2016) . This study indicated that Weibull is the best distribution to model the stump diameter frequency distribution. This result is also supported by research conducted for *Quercus persica* forests in Iran in 2015 (Mehrdad Mirzaei et al., 2016). The Weibull distribution is also a best distribution to model the frequency distribution of diameter and height in Vietnam (Bui Manh Hung et al., 2017; Nguyen Van Trieu et al., 2018).

According to the results of this study, the Power function was the best function to simulate the relationship between the base diameter, total height and volume of *Acacia mangium*. These results are also consistent with previous studies in Mexico and Turkey (Jose Javier Corral-Rivas et al., 2007; Ramazan Özçelík et al., 2010). These studies also showed that the parameters of the power function were significant different from zero. It was also found in the results of this study.

4.2. The volume prediction

The power function was the best function to simulate the relationship between the base diameter and volume of acacia trees. So, it was used to calculate and predict the tree volume. Two volume tables were established for each cluster. Currently, this kind of volume prediction tables based on the stump diameter are very scanty in Vietnam. This is a very good base for Ba Vi forest rangers to use. These tables can be used for other areas with similar soil and climate conditions. The volume table is an important scientific basis for determining the lost tree volume. And it may be the basis to determine a punishment frame for people who illegally fell trees in the study area and other areas with similar conditions.

5. CONCLUSION

The study divided the acacia community into two distinct clusters based on growth variables. The mean value of cluster 1 was also larger than cluster 2 by approximately 9 cm. The frequency distribution of cluster 1 was right-skewed, while that of cluster 2 was left-skewed. Weibull is the best distribution to model the stump diameter frequency distribution. The stump diameter had the strongest and most co-trending relationship with diameter at breast height, then crown width diameter, total height and finally commercial height. The study indicated that the Power function was the best function to simulate the relationship between the base diameter, total height and volume of *Acacia mangium*. The Power function was also used to construct two volume prediction tables. These tables can be used in Ba Vi and other areas with similar conditions. They are also the basis for determining the volume of trees that have been lost, determining the penalty frame for illegal logging people.

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ĐẶC ĐIỂM ĐƯỜNG KÍNH GỐC VÀ BẢNG THỂ TÍCH CHO RỪNG KEO TAI TƯỢNG TẠI BA VÌ, VIỆT NAM

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TÓM TẮT

Đường kính gốc cây có vai trò lớn trong quản lý tài nguyên rừng. Nghiên cứu đã sử dụng số liệu từ 23 ô tiêu chuẩn. Kết quả cho thấy khu vực rừng Keo được phân thành 2 nhóm. Đường kính trung bình của nhóm 1 lớn hơn nhóm 2. Phân bố tần số đường kính gốc của nhóm 1 có dạng lệch phải nhiều hơn. Nghiên cứu đã kiểm tra 5 phân bố lý thuyết bao gồm Normal, Lognormal, Weibull, SHASH, Johnson. Kết quả cho thấy rằng phân bố Weibull là tốt nhất để mô hình hóa phân bố số cây theo đường kính gốc. Tương quan giữa đường kính gốc và đường kính ngang ngực, chiều cao vút ngọn, thể tích cây được mô phỏng tốt nhất bằng hàm Power. Tương quan giữa đường kính gốc và đường kính ngang ngực, các tham số của phương trình Power cho nhóm 1 là 0,669 và 1,056. Trong khi đó, các tham số này của nhóm 2 lần lượt là 0,708 và 1,041. Tuy nhiên, hàm bậc ba lại là hàm tốt nhất để mô phỏng tương quan giữa đường kính gốc và chiều cao vút ngọn của nhóm 2. Hàm Power cũng đã được sử dụng để xây dựng hai bảng dự đoán trữ lượng cho hai nhóm. Những bảng này sẽ giúp lực lượng kiểm lâm Ba Vì và các khu vực khác có điều kiện tương tự để truy tìm thể tích cây bị mất, góp phần quản lý rừng bền vững, hiệu quả.

Từ khóa: Ba Vì, biểu thể tích, đường kính gốc, Keo tai tượng, phân tích đa biến.

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