MINISTRY OF AGRICULTURE AND RURAL DEVELOPMENT
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RESEARCHING CARBON STOCK DYNAMICS OF PURE (*DENDROCALAMUS BARBATUS* HSUEH ET D.Z.LI) PLANTATIONS IN THANH HOA PROVINCE

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SUMMARY OF DOCTORAL DISSERTATION IN FORESTRY

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PREFACE

1. The necessity of the dissertation

Being multi-purpose and economically highly valued, *Dendrocalamus barbatus* Hsueh et D.A.Li has been chosen as the major plant by many localities for its one-time planting and long-lasting multiple-time exploitation. With about 79,457 ha, Thanh Hoa ranks first among the largest *Dendrocalamus barbatus* Hsueh et D.A.Li plantations in the country, in which some districts have concentrated planting areas such as Quan Hoa, Lang Chanh, Ngoc Lac and Ba Thuoc. In addition to its economic and social value, *Dendrocalamus barbatus* Hsueh et D.A.Li also plays an important role in protecting the environment and absorbing greenhouse gases. The current studies on the plant simply focus on planting, propagating, exploiting techniques, etc. No research has been made on carbon stock dynamics of *Dendrocalamus barbatus* Hsueh et D.A.Li forest during the business operations, which may be fundamental for sustainable forest management and payment for forest environmental services. Thus, the production of this dissertation with title "***Researching carbon stock dynamics of pure Dendrocalamus barbatus Hsueh et DALi plantations in Thanh Hoa Province***" is necessary and significant both scientifically and practically to satisfy such visible need.

2. Objectives of the research

2.1. Scientific objectives

- Determing the biomass and carbon stock of individual tree and in pure plantations of the *Dendrocalamus barbatus* Hsueh et D.A.Li species in Thanh Hoa Province.
- Estimating biomass dynamics and carbon stock in pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantations in Thanh Hoa province.

2.2. Practical objectives

- Suggesting solutions to contribute to sustainable management and maintenance of carbon sinks in pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantations in Thanh Hoa province.

- Developing equations for predicting biomass, carbon stock and biomass dynamics, carbon dynamics in pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantations in Thanh Hoa province.

3. Scientific and practical significance of the dissertation

3.1. Scientific significance

The research results are supplemented to the current results on biomass and carbon stock dynamics, contributing to measure the value in environmental protection of pure *Dendrocalamus barbatus* Hsueh et D. Z.Li plantations in Thanh Hoa province

3.2. Practical significance

The research results are scientific basis for sustainable management of pure *Dendrocalamus barbatus* Hsueh et D. Z.Li plantations, maintenance of carbon sink and development of equations to quickly measure biomass and carbon stock of such forests in Thanh Hoa province.

4. New contributions of the dissertation

- Determining the dynamics on biomass and carbon stock of *Dendrocalamus barbatus* Hsueh et D. Z.Li plantations, including the available biomass and carbon stock in the forests; the biomass and carbon stock removed from the forests during the business process.
- Developing allometric equations to quickly estimate the biomass and carbon stock of individual trees and in *Dendrocalamus barbatus* Hsueh et D. Z.Li forests.

5. Object and scope of the research

5.1. Research object: Pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantations.

5.2. Research scope:

+ Regarding biomass and carbon of individual tree: To study the stem, branches, leaves and culm; develop biomass and carbon prediction equations for individual tree by ages. About the roots, research has been made for the whole forest, not for individual tree yet.

+ Regarding biomass and carbon stock in *Dendrocalamus barbatus* Hsueh et D.A.Li forests: The research is carried out to determine fresh and dry biomass, the amount of carbon sequestered in *Dendrocalamus barbatus* Hsueh et

D.A.Li forests, including the biomass and carbon stock in *Dendrocalamus barbatus* Hsueh et D.A.Li layer, ground vegetation, litter and in the underground roots of the species, to estimate the biomass and carbon dynamics of *Dendrocalamus barbatus* Hsueh et D.A.Li forests. However, the dissertation has not yet studied the carbon stock in forest soil, nor has it analyzed the carbon content in ground vegetation and litter, but instead using a conversion coefficient of 0.5 proposed by the IPCC.

+ In additions, the effects of site conditions on biomass and carbon sequestration of *Dendrocalamus barbatus* Hsueh et D.A.Li forests have not yet been studied in the dissertation.

- Location:

Four districts in Thanh Hoa province, specifically Ba Thuoc district, Lang Chanh district, Ngoc Lac district and Quan Hoa district, with the largest area of *Dendrocalamus barbatus* Hsueh et D.A.Li plantations are selected to carry out this research.

5. Structure of the dissertation

The dissertation consisting of 131 pages with 30 tables, 30 figures and 4 images, is structured as follows:

Preface: 4 pages; Chapter 1: Literature review: 27 pages; Chapter 2: Contents and research methods: 14 pages; Chapter 3: Research results and discussion: 67 pages; Conclusion, limitations and recommendations: 3 pages, References: 15 pages

Chapter 1
LITERATURE REVIEW

1.1.In the world:

The authors who study forest biomass include Riley, G.A (1944), Steemann Nielsen, E (1954), Fleming, RH (1957) and Christensen (1997)... Biomass research methods are carbon dioxide; "Chlorophyll"; Oxygen; harvesting, in which tree sampling is most commonly used.

Brown and Pearce (1994), Wanthongchai and Piriyayota (2006), Druba (2008), Arnor et al. (2002), etc, are outstanding researchers related to carbon

sequestration. According to McKenzie (2001), carbon is concentrated in four main parts of the ecosystem, namely ground vegetation, litter, roots and forest soil.

Biomass and carbon of bamboo forests have been studied by some typical authors such as: Fayolle (2013) Seethalakshmi (2016), Syam and Sruthi (2017), Nath et al. (2015), Zhang (2014) ... INBAR (2019) provided guidance on how to measure biomass and carbon stock of bamboo forests through culm. The method was to cut down standard trees, from which, develop the biomass and carbon stock prediction equations based on survey factors such as $D_{1,3}$, Hvn and tree age. Bernard (2007), Dai Qihui, (1998), Fu and Xiao (1996) and Xu Tiansen (1998) carried out research on *Dendrocalamus barbatus* Hsueh et D.A.Li.

1.2. In Vietnam:

Forest biomass researching is conducted quite later than that in the world. However, remarkable achievements have been initially obtained with some related research authors such as: Vo Dai Hai, Bao Huy, Vien Ngoc Nam, Vu Tan Phuong, Nguyen Thanh Tien, Dang Thinh Trieu ...

Although there are not many specific studies on biomass and carbon stock of bamboo forests and *Dendrocalamus barbatus* Hsueh et D.A.Li forests specifically, some researchers can be listed namely Le Xuan Truong, Nguyen Dinh Hung, Nguyen Xuan Dong ...

Studies on *Dendrocalamus barbatus* Hsueh et D.A.Li so far have been fairly comprehensive in propagation, planting, tending techniques, pests and diseases, exploitation, ... Typical authors in this field include Ngo Quang De, Nguyen Quang Lien, Le Xuan Truong, Dang Thinh Trieu, Bui Thi Huyen ...

1.3. General discussion

In recent years, many studies have been made on *Dendrocalamus barbatus* Hsueh et D.A.Li, from breeding to planting techniques... But, none of them provide enough adequate and systematic information on carbon stock dynamics of this bamboo species, including the carbon amount removed from the forest every year in order to quantify the environmental value of *Dendrocalamus barbatus* Hsueh et D.A.Li forest during the business process.

The main methods, which are also used to carry out the research in this dissertation, comprise using standard plants, sampling the biomass of dried plant parts and analyzing the carbon content in the laboratory or applying the biomass-carbon conversion coefficient proposed by IPCC (2003).

Chapter 2
CONTENTS AND METHODS

2.1. Research contents

- Studying the biomass of individual *Dendrocalamus barbatus* Hsueh et D.A.Li trees.
- Studying the biomass in pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantations in Thanh Hoa province.
- Studying carbon sequestration capacity of pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantations in Thanh Hoa province.
- Studying biomass dynamics and carbon stock dynamics in pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantations in Thanh Hoa province.
- Proposing solutions to contribute to sustainable management, maintenance of carbon sinks and to quickly determine biomass and carbon stock of pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantations in Thanh Hoa province.

2.2. Research methods

2.3.1. Viewpoints and approaches:

2.3.1.1. Topic viewpoints

Studying the biomass and carbon stock dynamics of *Dendrocalamus barbatus* Hsueh et D.A.Li forests is based on a **quantitative viewpoint**. The research will not study the dynamics (changes of tree and forest status) in the development process such as bamboo shoots and tree growth and development..., instead, focus only on the amount of biomass and carbon sequestered in the forest at the time of studying as well as its dynamics by forest age, including the biomass and carbon stock that is available in the forest and taken out of the woods during business.

Dendrocalamus barbatus Hsueh et D.A.Li forest is made up of individual trees, so the thesis will study the dynamics on biomass and carbon stock of both

individual trees and the forest. Furthermore, other components of *Dendrocalamus barbatus* Hsueh et D.A.Li forest such as ground vegetation and litter will also be subjects of this research regarding biomass and carbon storage.

2.3.1.2. The approaches of the research.

- *Systematic approach*
- *Research approach on located and temporary plots*
- *Approach by tree age and culm diameter*
- *Approach by forest age*
- *Approach by research locations.*

2.3.2. Method of secondary information and data collection

The research inherits the available information, data and research projects such as: data on natural, economic and social conditions of the 4 districts; data on present conditions of *Dendrocalamus barbatus* Hsueh et D.A.Li forests and related documents.

2.3.3. Method of on-site investigation and data collection

2.3.2.1. Site selection and quadrat placement

The study is conducted in 4 districts such as Ngoc Lac, Lang Chanh, Ba Thuoc and Quan Hoa. In each district 3 communes are selected as followed:

+ In Ngoc Lac district: Minh Son, Minh Tien and My Tan communes.

+ In Lang Chanh district: Tan Phuc, Quang Hien, Dong Dendrocalamus barbatus Hsueh et D.A.Li communes.

+ In Ba Thuoc district: Tan Lap, Dien Quang and Dendrocalamus barbatus Hsueh et D.A.Li Trung communes.

+ In Quan Hoa district: Nam Tien, Hoi Xuan, Xuan Phu communes.

The age of *Dendrocalamus barbatus* Hsueh et D.A.Li forest is divided into 6 categories:

Age class I: 1-5 years old; Age class II: 6-10 years old;
Age class III: 11-15 years old; Age class IV: 16-20 years old;
Age class V: 21-25 years old; Age class VI: over 25 years old.

In each studied district, 12 quadrats of 1000 m^2 (40m x 25m) are placed to collect data on growth, biomass and carbon stock in the forest.

2.3.3.2. Investigation and data collection on density and growth of Dendrocalamus barbatus Hsueh et D.A.Li

In each quadrat, the trees and clumps are numbered. Ages of individual plants are determined such as: age 1, age 2, age 3 and greater than or equal to (≥) age 4. The diameter (cm) and height (m) of the plants are measured and the quantity of trees/ha is counted.

2.3.3.3. Method for collecting biomass and carbon stock data

a) Method of collecting biomass data of Dendrocalamus barbatus Hsueh et D.A.Li individuals

The tree's diameter is divided into the following classes: <8.0 cm, 8.0-8.9 cm, 9.0-9.9 cm, 10.0-10.9 cm, 11.0-11, 9 cm, and ≥ 12 cm. The total number of the cut standard trees is 192 of which 48 trees is categorised for each age class. After cutting, the diameter at 1.3m and the length of the tree are measured. After that, the tree is divided into 3 parts such as: culm, branches and leaves. Fresh biomass is determined by weighing the trees in the forest. The rhizome is digged under the standard tree with the soil being removed and then weighed for fresh biomass.

b) Collecting biomass data of Dendrocalamus barbatus Hsueh et D.A.Li root

The biomass of the species root is determined according to 8 sub-plots arranged around *Dendrocalamus barbatus* Hsueh et D.A.Li clump, after that the total root biomass of its forest is calculated. Each sub-plot has an area of 0.25 m^2 (0.5 m x 0.5 m). The sub-plots is digged deep down to 50 cm, then sieving and collecting all the *Dendrocalamus barbatus* Hsueh et D.A.Li roots are sieved and collected. Fresh biomass is determined by immediately weighing the roots in the forest.

c) Collecting biomass data of ground vegetation

In each 1000 m^2 quadrat, 5 secondary plots are arranged (4 plots in the 4 corners and 1 plot in the middle of the quadrat) with an area of 25m^2 (5m x 5m). The total number of secondary plots is 240 (60 plots per district). In the secondary plots, all the ground vegetation are collected and weighed to

determine fresh biomass.

d) Collecting biomass data of litter:

One $1m^2$ sub-plot is placed in the middle of the $25m^2$ secondary plot, where, all the litter is gathered and weighed on site to calculate their fresh biomass.

e) Calculating Dendrocalamus barbatus Hsueh et D.A.Li biomass removed from the forest

Located plots are arranged to monitor the exploitation of the species for 3 years. In each district, for each age class, 1 located quadrat is placed for monitoring. There are total 24 quadrats. The data on the age, diameter, height and biomass of each exploited *Dendrocalamus barbatus* Hsueh et D.A.Li tree is collected every year. Parts the species removed from the forest including culm and branches is weighed on site in the forest to determine fresh biomass.

2.3.4. Laboratory sample analysis

2.3.4.1. Sample drying for biomass determination

Fresh biomass samples (parts of *Dendrocalamus barbatus* Hsueh et D.A.Li trees, ground vegetation, litter, and the species roots), after being collected, will be dried at 105^oC in the laboratory to constant weight for determining dry biomass of each part.

2.3.4.2. Carbon content analysis in biomass samples

+ Analysis of carbon content in parts of *Dendrocalamus barbatus* Hsueh et D.A.Li trees is conducted according to the method of Walkey and Black (the principle of the method is to use oxidation of organic chemicals with K2Cr2O7 solution in H2SO4 acid)

+ Determination of carbon amount in ground vegetation and litter: dry biomass to carbon conversion coefficient of 0.5 recommended by IPCC (2003) is applied in this thesis.

2.3.4. Data analysis and processing

- Mathematical statistics method, Excel and SPSS 22.0 in forestry are applied to process the data. Some of the statistical tools are also used such as descriptive statistics, sample homogeneity testing, regression variance analysis.

Chapter 3.
RESEARCH RESULTS AND DISCUSSION

3.1. Research on biomass of individual *Dendrocalamus barbatus* Hsueh et D.A.Li plants

3.1.1. Fresh biomass of individual plants

3.1.1.1. Fresh biomass by diameter and age

The results show no difference in fresh biomass of individual plants by age and diameter classes among the research sites. Accordingly, the thesis has synthetized the data on the fresh biomass of individual trees in the study locations, as presented in Table 3.1 below.

Table 3.1. Fresh biomass of individual trees by diameter and age

Diameter class (cm)	Biomass by age (kg/tree)				
	1	2	3	≥4	Average
< 8	19.9±1.1	22.4±2.2	22.3±2.4	23.0±2.9	22.0±2.5
8.0-8.9	24.1±2.3	27.2±7.1	28.7±3.9	29.3±2.6	27.4±5.2
9.0-9.9	30.9±5.3	34.5±5.5	36.6±3.4	35.9±7.3	34.3±5.7
10.0-10.9	35.9±4.3	38.6±2.9	39.5±8.6	39.2±5.4	38.3±6.0
11.0-11.9	38.4±5.3	42.9±7.6	43.5±9.2	43.8±7.1	41.0±7.4
≥12	43.6±4.1	47.7±6.5	47.9±2.7	48.2±1.8	46.5±7.1

Table 3.1 shows that fresh biomass of a *Dendrocalamus barbatus* Hsueh et D.A.Li individual is directly proportional to its diameter and age. The lowest biomass (19.9 kg/tree) is of age 1 plant with diameter <8 cm and the highest (42.8 kg/tree) is of ≥4 year-old tree with a diameter of ≥ 12 cm.

3.1.1.2. Fresh biomass structure of individual tree

The fresh biomass of *Dendrocalamus barbatus* Hsueh et D.A.Li individual plants is mainly concentrated in the culm (70.0%), then in branches (13.1%), rhizome (8.9%) and leaves (8.0%).

3.1.2. Dry biomass of individual plants

3.1.2.1. Dry biomass of individual plants by diameter and age

The research results are presented in table 3.2.

Table 3.2. Dry biomass of individual plants by diameter and age

Diameter class (cm)	Biomass by age (kg/tree)				Average (kg/tree)
	1	2	3	≥4	
< 8	10.2±0.9	11.0±1.2	11.5±0.7	12.2±1.7	11.2±1.4
8.0-8.9	12.5±1.4	13.1±2.9	14.3±2.0	15.5±1.5	13.7±2.4
9.0-9.9	14.9±2.4	16.1±2.6	18.4±1.8	17.9±4.0	16.7±2.9
10.0-10.9	17.3±2.2	18.8±1.7	19.5±4.2	19.4±2.9	18.7±3.1
11.0-11.9	18.8±2.5	21.3±3.9	21.8±5.1	21.9±2.7	20.3±3.8
≥12	21.3±2.1	23.5±4.4	23.6±1.7	23.8±1.4	22.9±3.0

Dry biomass of individual *Dendrocalamus barbatus* Hsueh et D.A.Li plant increases gradually with the tree diameter as shown in the above data. The average amount of dry biomass ranges from 11.2 to 22.9 kg/tree, corresponding to <8cm to ≥ 12 cm in diameter. In terms of age, the dry biomass especially fluctuates the most in the trees aged 1 to 2 while not much change is found in the trees aged 3 to 4.

3.1.2.2. Dry biomass structure of individual plant parts

Dry biomass of an individual *Dendrocalamus barbatus* Hsueh et D.A.Li plant concentrates significantly on culm (71.4%), followed by branches (13.2%), rhizome (8.9 %) and leaves (6.5%).

3.1.3. Biomass dynamics by age of Dendrocalamus barbatus Hsueh et D.A.Li plant

Biomass dynamics by the age of *Dendrocalamus barbatus* Hsueh et D.A.Li plants is a contiguous motor state and experiences through 3 phases: regeneration, growth and development. The research results shows that the biomass of the age 2 plants increases from 1.05 to 1.13 times compared to which of age 1 trees. The same happens to the biomass of the trees at the age 3, which is 1.02-1.14 times higher than that of the age 2 ones. A *Dendrocalamus barbatus* Hsueh et D.A.Li plant at the ages of 3 and 4 years or older has almost stable biomass.

In terms of diameter class, the biomass of individual plants at age 1 is

always lower than that of individual plants at ages 2, 3, 4. There is not much change in the biomass of individual plants aged 2, 3 and 4, especially at the diameter of more than 10 cm.

3.1.4. Relationship between fresh biomass and dry biomass of individual plants with survey factors

Table 3.3. Correlation between fresh biomass and dry biomass of individual plants with survey factors

No.	Plant age	Content	R^2	Std	Sig R	Sig Ta1	PT mark
I	**Allometric equations between fresh biomass and survey factors $D_{1.3}$, H_{vn}**						
1	1	$LnSKT_{age\ 1} = 0,396 + 1,386xLnD_{1,3}$	0.73	0.13	0.00	0.00	3.1
2	2, 3, 4	$LnSKT_{age\ 2,3,4} = -0,093 + 0,931xLnD_{1,3} + 0,650xLnHvn$	0.73	0.14	0.00	0.00	3.2
3	General	$LnSKT_{general} = 0,017 + 1,049xlnD_{1,3} + 0,498xlnHvn$	0.69	0.14	0.00	0.00	3.3
II	**Allometric equations between dry biomass and survey factors $D_{1.3}$, H_{vn}**						
1	1	$LnSKK_{age\ 1} = -0,078 + 1,281xLnD_{1,3}$	0.70	0.13	0.00	0.00	3.4
2	2,3,4	$LnSKK2,3,4 = -0,601 + 0,943xLnD_{1,3} + 0,561xLnHvn$	0.70	0.14	0.00	0.00	3.5
3	General	$LnSKK_{general} = -0,494 + 1,032xLnD_{1,3} + 0,433xLnHvn$	0.66	0.15	0.00	0.00	3.6

As a result, 6 equations are built from Equation 3.1 to Equation 3.6, which exhibit well the relationship between fresh and dry biomass by tree age with $D_{1,3}$, Hvn. In case the age of individual Dendrocalamus barbatus Hsueh et D.A.Li trees is unidentified, the equations 3.3 and 3.6 can be used to quickly determine fresh and dry biomass of the individual plants.

3.2. Research on biomass of Dendrocalamus barbatus Hsueh et D.A.Li forests

3.2.1. Fresh biomass of Dendrocalamus barbatus Hsueh et D.A.Li forests

3.2.1.1. Fresh biomass of Dendrocalamus barbatus Hsueh et D.A.Li layer

The fresh biomass of Dendrocalamus barbatus Hsueh et D.A.Li layer includes total biomass of it parts (culm, branches, leaves and rhizome). Fresh

biomass of *Dendrocalamus barbatus* Hsueh et D.A.Li varies from 37.05 to 77.96 tons/ha with an average of 60.96 tons/ha at all age classes and study sites. Culm is the part that gathers the most biomass with 70.02%, followed by branches (13.19%), rhizome (9.45%) and leaves have the least (8.23%).

3.2.1.2. Fresh biomass of Dendrocalamus barbatus Hsueh et D.A.Li roots

The fresh biomass of *Dendrocalamus barbatus* Hsueh et D.A.Li roots is 3.48-6.30 tons/ha and averaged 5.56 tons/ha. The biomass in the root is half of which in the rhizome and about 2/3 of the branch biomass.

3.2.1.3. Fresh biomass of ground vegetation and litter

A fluctuation is shown in the fresh biomass of ground vegetation among the forest age classes, in which, the amount reaches its peak when the forest is at age class I and rocks bottem when the forest is at age class VI, with an average of 1.18 tons/ha.

On the other hand, the fresh biomass of litter is in the opposite direction. The average amount of the forests age classes and in study sites is 3.40 tons/ha.

3.2.1.4. Fresh biomass of Dendrocalamus barbatus Hsueh et D.A.Li forest

The total fresh biomass of *Dendrocalamus barbatus* Hsueh et D.A.Li forest is constituted by the biomass of *Dendrocalamus barbatus* Hsueh et D.A.Li layer, of ground vegetation, litter and of its roots. The average fresh biomass in this kind of forest at all forest age classes and study locations reaches 71.06 tons/ha, concentrating mainly in the *Dendrocalamus barbatus* Hsueh et D.A.Li layer (accounting for 85.66%); its roots (accounting for 7.72%), litter (accounting for 4.88%) and lastly ground vegetation with the lowest percentage (accounting for 1.73%).

3.2.3. Study on dry biomass of Dendrocalamus barbatus Hsueh et D.A.Li forest

3.2.3.1. Dry biomass of Dendrocalamus barbatus Hsueh et D.A.Li layer

The dry biomass of the species layer varies strongly among the forest age classes and the studied districts. The amount of biomass ranges from 17.60 to 38.28 tons/ha with an average of 30.25 tons/ha.

With 70.47%, the culm, again, concentrates the most amount of dry biomass,

followed by the branches and rhizome with 13.38% and 9.42% respectively while the least amount falls in the leaves (6.72%).

3.2.3.2. Dry biomass of Dendrocalamus barbatus Hsueh et D.A.Li roots

The lowest dry biomass of *Dendrocalamus barbatus* Hsueh et D.A.Li roots is 1.81 tons/ha, corresponding to forest age class I and the highest is 3.20 tons/ha when the forest is at age class V. The average at all forest age classes and study sites is 2.83 tons/ha.

3.2.3.3. Dry biomass of ground vegetation and litter

The study results show that the dry biomass of ground vegetation and litter does not vary significantly among the forest age classes and study sites. On average, dry biomass of ground vegetation and litter are 0.51 tons/ha and 2.23 tons/ha respectively.

3.2.3.4. Dry biomass of pure Dendrocalamus barbatus Hsueh et D.A.Li forests in Thanh Hoa province

Dendrocalamus barbatus Hsueh et D.A.Li layer is the place that gathers the highest dry biomass in the forest of this species, averaging 84.14%. Meanwhile, *Dendrocalamus barbatus* Hsueh et D.A.Li roots occupies 7.88%, litter accounts for 6.56% and ground vegetation is the lowest with only 1.42%. The dry biomass of Dendrocalamus barbatus Hsueh et D.A.Li forest is highest when the forest is at age class V (39.89 tons/ha) and lowest when the forest is at age class I (24.66 tons/ha) and averaged 35.95 tons/ha.

3.2.3.5. Relationship between fresh biomass and dry biomass of Dendrocalamus barbatus Hsueh et D.A.Li forest with survey factors.

Table 3.4. Correlation between fresh and dry biomass of *Dendrocalamus barbatus* Hsueh et D.A.Li forest with survey factors

No.	Equation name	R^2	Std	Sig.Ta	Sig.Tb	PT mark
I	**Relationship between fresh biomass and survey factors**					
1	$LnSK_{Fresh}$= - 6,216+ 0,18xln$D_{1,3}^2$xHvn+ 1,2xlnN	0.86	0.07	0.00	0.00	3.7
II	**Relationship between dry biomass and survey factors**					
1	SK_{Dry} = -10,429 + 0,009x$D_{1,3}^2$xHvn + 0,017xN	0.85	2.60	0.00	0.00	3.8

As a result, two allometric equations between fresh biomass and dry biomass of *Dendrocalamus barbatus* Hsueh et D.A.Li forest with survey factors have been developed (equations 3.7 and 3.8).

3.3. Study on carbon sequestration capacity of *Dendrocalamus barbatus* Hsueh et D.A.Li forest

3.3.1. Carbon stock in individual Dendrocalamus barbatus Hsueh et D.A.Li plant

3.3.1.1. Carbon content in parts of individual Dendrocalamus barbatus Hsueh et D.A.Li tree

Table 3.5. Carbon content in parts of individual Dendrocalamus barbatus Hsueh et D.A.Li tree

Age	Carbon content in parts (%)			
	Culm	Rhizome	Branches	Leaves
1	50.9	48.1	48.2	42.0
2	52.2	51.3	49.9	43.0
3	52.7	52.2	50.7	42.9
≥4	53.6	53.1	50.4	42.2
Average	**52.3**	**51.2**	**49.8**	**42.6**

According to the results, the carbon content in culm, branches, leaves, and rhizome is different. The culm is the place where the carbon concentrates the most with an average of 52.3%, followed by the rhizomes (51.2%) and the branches (49.8 %), while the least amount falls in the leaves (42.6%).

3.3.1.2. Carbon storage of individual Dendrocalamus barbatus Hsueh et D.A.Li plant by diameter and age

Table 3.6. Carbon stock in individual plant by diameter and age

Diameter (cm)	Carbon amount by tree age (kg/tree)				Average (kg/tree)
	1	2	3	≥4	
< 8	5.1±0.3	5.7±0.7	6.0±0.5	6.4±0.9	5.8±0.8
8.0-8.9	6.3±0.7	6.8±1.6	7.4±1.1	8.1±0.8	7.0±1.3
9.0-9.9	7.5±1.3	8.2±1.2	9.5±1.0	9.5±2.0	8.6±1.6
10.0-10.9	8.7±1.2	9.8±0.9	10.1±2.2	10.2±1.4	9.6±1.7

Diameter (cm)	Carbon amount by tree age (kg/tree)				Average (kg/tree)
	1	2	3	≥4	
11.0-11.9	9.3±1.2	11.2±2.0	11.0±2.6	11.2±1.4	10.3±2.0
≥12	10.4±1.2	12.3±2.1	12.3±0.7	12.3±0.7	11.6±1.6

The amount of carbon sequestered in a *Dendrocalamus barbatus* Hsueh et D.A.Li individual on average ranges from 5.8 to 11.6 kg/tree, corresponding to the tree diameter of <8 cm to ≥ 12 cm. In which, in terms of tree age, the carbon amount increases from age 1 to age ≥ 4 trees, but only sharply increases in the ages of 1 and 2 while there is not much difference between age 3 and age ≥ 4 at the same diameter class.

3.3.1.3. Carbon dynamics of individual Dendrocalamus barbatus Hsueh et D.A.Li trees by age

The carbon stock in individual trees at age 1 varies from 5.1 to 10.4 kg/tree. The amount rises 1.07-1.2 times when the tree reaches 2 years old. At the age of 3, the amount of carbon increases from 1.02 to 1.14 times compared to the 2-year-old plants. When plants are 3 and 4 years old, the amount of carbon does not change much, or in other words, the carbon stock is stable at the age of 3 and 4.

3.3.1.4. Carbon structure in individual plant parts

The signigicant percentage of carbon stock of an individual is in culm with 73.0%. The rhizome and the leaves occupy the modest amount with 8.8% and 5.4%. The carbon stock increases gradually from age 1 to age 4, specifically, 6.2 kg/tree when the tree is at age 1, and rising to 6.3 kg/tree, 6.5 kg/tree and 6.9 kg/tree for 2, 3 and ≥ 4 years old trees.

3.3.2. Carbon stock of Dendrocalamus barbatus Hsueh et D.A.Li layer

There is a gradual increase in the carbon sequestration amount of the *Dendrocalamus barbatus* Hsueh et D.A.Li layer over time. The amount is lowest at forest age class I with an average of 14.41 tons/ha and highest at age class V, reaching 17.25 tons/ha. In this layer, carbon is sequestered considerably in the culm with 72.34%, followed by branches with 13.13%; branches with 9.35% and slightly in leaves with 5.18% only.

3.3.3. Carbon stock in Dendrocalamus barbatus Hsueh et D.A.Li roots

At forest age class I, the average amount of carbon sequestered in the roots is 1.09 tons/ha. An increase to 1.15 tons/ha is made when the forest is at age class II, however, at the age classes III and VI, the little change is found with an average of 1.17 tons/ha.

3.3.4. Carbon stock in ground vegetation and litter

Opposite to the increase in forest age, a gradual decrease is witnessed in amount of carbon stock in ground vegetation, ranging from 0.18 to 0.21 tons/ha, with an average of 0.19 tons/ha. The amount of carbon in litter is about 0.66-0.79 tons/ha, averaging 0.73 tons/ha.

3.3.5. Carbon stock in pure Dendrocalamus barbatus Hsueh et D.A.Li plantations

The amount of carbon stored in Dendrocalamus barbatus Hsueh et D.A.Li forest ranges from 11.09 to 20.54 tons/ha with an average of 17.57 tons/ha. The Dendrocalamus barbatus Hsueh et D.A.Li layer and its roots occupy the most percentage of carbon stock with averages of 88.07% and 6.66%. The amount of carbon sequestered in litter stays in the middle with 4.16%. The ground vegetation stores the least amount of carbon with 1.11%.

3.3.6. Relationship between carbon stock with survey factors

Table 3.7. Correlation between carbon stock in individual tree and forest of Dendrocalamus barbatus Hsueh et D.A.Li

No.	Equation	R^2	Std	Sig R	Sig Ta1	Sig Ta2	Sig Ta3	PT mark
I	**Correlation of carbon stock in individual tree**							
1	$LnC_1 = -0,619 + 1,212xLnD_{1,3}$	0.66	0.14	0.00	0.00	0.00		3.9
2	$LnC_{2,3,4} = -1,403 + 0,911xLnD_{1,3} + 0,647xLnHvn$	0.69	0.15	0.00	0.00	0.00		3.10
3	$LnC_{general} = -1,207 + 0,962xlnD_{1,3} + 0,514xLnHvn$	0.65	0.15	0.00	0.00	0.00		3.11
II	**Correlation of carbon stock in fores**							
1	$LnC_{LP} = -2,326 + 0,860xLnD_{1,3} + 0,102xLnHvn + 0,988xLnN$	0.97	0.03	0.00	0.00	0.02	0.00	3.12

- For individual plants: 3 equations (from 3.9 to 3.11) have been formulated to

quickly determine the carbon stock through $D_{1.3}$ and Hvn. In case the age of individual trees is unknown, equation 3.11 can be applied to tree ages in general.

- For *Dendrocalamus barbatus* Hsueh et D.A.Li forest: equation 3.12 has been built to well represent the relationship between the carbon stock of the forest with survey factors $D_{1,3}$, Hvn and N.

3.4. Study on biomass dynamics and carbon stock dynamics of Dendrocalamus barbatus Hsueh et D.A.Li forest

3.4.1. Biomass dynamics of Dendrocalamus barbatus Hsueh et D.A.Li forest

3.4.1.1. The amount of dry biomass removed annually from Dendrocalamus barbatus Hsueh et D.A.Li forest

The average dry biomass removed annually from the forest is about 5.1 tons/ha/year at forest age class I and 9.81 tons/ha/year at forest age class IV. The biomass removed at age class II is about 40% higher than that at age class I. From age classes II to IV, the removed biomass also witnesses a rapid increase from 7.78 to 9.18 tons/ha/year. There is a slight difference between the biomass removed from the forest at age classes IV and V, averaging 9.18 - 9.32 tons/ha.

In terms of structure, the biomass removed from the forest is mainly concentrated in the culm (accounting for 80%), the rest is in branches (accounting for 20% of the biomass removed from the forest).

3.4.1.2. Biomass dynamics of pure Dendrocalamus barbatus Hsueh et D.A.Li plantations

A great amount of biomass is removed from *Dendrocalamus barbatus* Hsueh et D.A.Li forests. At forest age class I, the amount of biomass removed is 11.05 tons/ha, then increases by 5 times when the forest at age class II, reaching 49.93 tons/ha, and is highest at forest age class V with a reach of 250.45 tons/ha. On average, 12.5 tons of dry biomass is removed per hectare per year. Figure 3.25.

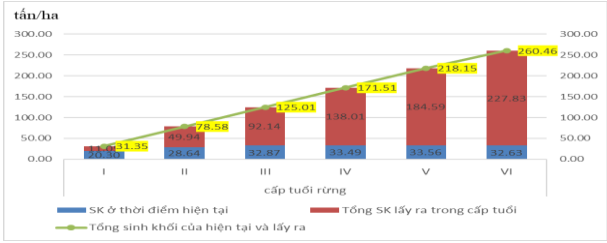

Figure 3.25. Biomass dynamics of pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantations

The results of comparing the biomass removed from the forest with the available biomass in the forest express that at the forest age class I, the biomass removed is only equal to 80% of the available biomass in the forest. In the forest age class II, the amount of biomass removed is almost 2 times higher than the existing biomass. Similarly, an increase is experienced at the forest age classes IV and V with 4.3 times and 5.5 times. At forest age class VI, the amount of biomass removed is 6.5 times higher than the current biomass of the forest and reaches 260.46 tons/ha.

3.4.2. Carbon dynamics of pure Dendrocalamus barbatus Hsueh et D.A.Li plantations in Thanh Hoa province

3.4.2.1. The amount of carbon removed from the forest every year

At the forest age class I, the amount of carbon removed from the forest is between 2.7 and 3.05 tons/ha/year. The carbon removed at age class II increases sharply and is 1.4 times higher than that at age class I. When the forest is at age class III the amount is 4.36 tons/ha, showing 8% higher than at age class II. It shows stable results in the amount of carbon removed from age class III to V and a decrease at age class VI. There is no significant difference in the amount of carbon removed from the forest among the districts Ba Thuoc, Quan Hoa and Lang Chanh. The amount of carbon removed in Ngoc Lac district is highest in all age groups.

3.4.2.2. Carbon dynamics of Dendrocalamus barbatus Hsueh et D.A.Li forest

Along with the carbon sequestration in Dendrocalamus barbatus Hsueh et D.A.Li forest at present time, a large amount of carbon has been removed

during the business operations. In particular, the amount of carbon removed from the forest is 5.80 tons/ha when the forest is at age class I and increases nearly 4 times at age class II with approximately 25.89 tons/ha. The amount increases about 22 tons/ha/5 years on average. At age class VI, the amount of carbon removed from the forest reaches 117.50 tons/ha, 7 times higher than the available carbon stock in Dendrocalamus barbatus Hsueh et D.A.Li forest (16.65 tons/ha) (Figure 3.27).

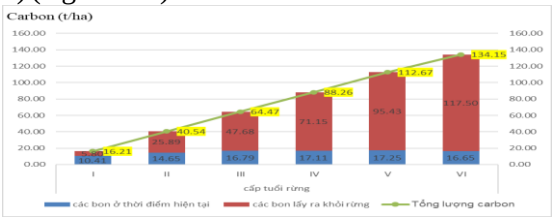

Figure 3.27. Carbon dynamics of pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantation

3.4.2.3. Models of biomass and carbon dynamics of Dendrocalamus barbatus Hsueh et D.A.Li plantation

As the results, models of biomass and carbon dynamics of *Dendrocalamus barbatus* Hsueh et D.A.Li plantation are presented in Table 3.13

Table 3.8. Models of biomass and carbon dynamics of *Dendrocalamus barbatus* Hsueh et D.A.Li plantation

No.	Equation	R^2	Std	Sig.Ta	Sig.Tb	PT mark
I	**Dry biomass dynamics model**					
1	$LnSKK_{ĐT}$ = - 4,561+ 1,0018xLnA + 0,856xLnN	0.98	0.093	0.00	0.00	3.13
II	**Carbon dynamics model**					
1	$LnC_{ĐT}$ = -5,381 + 0,992xLnA + 0,880xLnN	0.98	0.096	0.00	0.00	3.14

It is expresses that one equation (3.13) that represents the dry biomass dynamics well and one equation (3.14) which exhibits well carbon stock dynamics of *Dendrocalamus barbatus* Hsueh et D.A.Li forest by forest age and density. Therefore, the above equations can be used to quickly estimate

the biomass dynamics and carbon stock dynamics at the present and to be removed from the stand during the business process.

3.5. Proposing solutions to contribute to sustainable management, carbon sink maintenance and rapid determination of biomass, carbon stock in pure Dendrocalamus barbatus Hsueh et D.A.Li plantations in Thanh Hoa Province

3.5.1 Proposing solutions for sustainable management of Dendrocalamus barbatus Hsueh et D.A.Li forest and carbon sink maintenance.

3.5.1.1. General solutions

- Land and planning management: although the Provincial People's Committee has issued a Decision approving the Dendrocalamus barbatus Hsueh et D.A.Li intensive cultivation area, however, it is necessary to examine and evaluate the implementation of the plan.

- Production organization: It is a need to direct owners of normal growing areas to take care of and exploit sustainably. Low productivity areas need to promote rehabilitation of the forest.

3.5.1.2. Specific solutions

- Individual Dendrocalamus barbatus Hsueh et D.A.Li trees: The carbon stock in individual trees increases strongly from age 1 to age 2 and is stable when the trees turn 3 and ≥ 4 years old, so, only Dendrocalamus barbatus Hsueh et D.A.Li trees of 3 – 4 years and greater should be cut so as not to affect the maximum amount of carbon stock in the culm as well as the sustainability of the forest.

- The amount of carbon is a great increase from forest age class I to forest age class II, so the stable harvesting period is the forest age class II (the forest is in the 6th year onwards). When the forest is at age class VI (the forest is more than 25 years old) the amount of biomass and carbon stock begins to decrease compared to which at age class V. So technical measures in intensive culvation and rehabilitation of *Dendrocalamus barbatus* Hsueh et D.A.Li plantation are required to ensure stable growth and density of the forest (from 2500 to 2600 trees/ha). Degraded Dendrocalamus barbatus Hsueh et D.A.Li

forest should be destroyed and replanted with high yielding Dendrocalamus barbatus Hsueh et D.A.Li seedings.

- Forest exploitation should be carried out in the right time, from October of the previous year to March of the following year (starting when the bamboo shoots shape and finishing before the bamboo shoots grow). Besides, it is necessary to have training for forest owners on intensive farming techniques and exploitation of *Dendrocalamus barbatus* Hsueh et D.A.Li culm at the right age, right season, and how to select correct plants for sustainable forest development.

- Neither ground vegetation clearing nor litter collection are suggested because in addition to carbon sequestration, ground vegetation and litter also cover the ground, prevent erosion and nutrients washout.

3.5.2. Proposing method for quick determination of biomass and carbon stock in Dendrocalamus barbatus Hsueh et D.A.Li forest

3.5.2.1. Quick determination of fresh biomass, dry biomass and carbon stock of individual Dendrocalamus barbatus Hsueh et D.A.Li plant.

- *Fresh biomass*: allometric equations 3.1 to 3.3 should be used to determine fresh biomass of individual *Dendrocalamus barbatus* Hsueh et D.A.Li plant.

- *Dry biomass*: allometric equations 3.4 to 3.6 should be applied to determine dry biomass of individual *Dendrocalamus barbatus* Hsueh et D.A.Li plant.

- *Carbon stock*: equations 3.9 to 3.11 should be used to determine the amount of carbon sequestered in the individual *Dendrocalamus barbatus* Hsueh et D.A.Li plant.

3.5.2.2 Quick calculation of fresh biomass, dry biomass and carbon stock of the pure Dendrocalamus barbatus Hsueh et D.A.Li plantations

- The equations 3.7; 3.8 and 3.12 are available to determine the fresh, dry biomass and carbon stock of the forest.

3.5.2.3. Determination of biomass dynamics and carbon stock dynamics of Dendrocalamus barbatus Hsueh et D.A.Li forest

- The equations 3.13 and 3.14 should be applied to determine the dry biomass dynamics and carbon stock dynamics of *Dendrocalamus barbatus* Hsueh et D.A.Li forest.

CONCLUSION, LIMITATIONS, RECOMMENDATIONS

1. Conclusion

1.1. Biomass and carbon stock of individual plant

1.1. Biomass and carbon accumulate in individual plants

- Fresh biomass of *Dendrocalamus barbatus* Hsueh et D.A.Li individual ranges from 19.9 to 48.2 kg/tree, is mostly concentrated in culm (70.0%), then in branches (13.1%), rhizome (8.9%)) and leaves (8.0%). Dry biomass of an individual is between 10.2 and 23.8 kg/tree, in which, 71.4% is allocated in culm, 13.2% in branches, 8.9% in rhizome and 6.5% in leaves.

- The carbon content in the culm is 52.3% while which in the rhizome, branches and leaves is 51.2%, 49.8% and 42.6% respectively. The amount of carbon in a Dendrocalamus barbatus Hsueh et D.A.Li tree ranges from 5.1 to 12.3 kg/tree (the culm, again, occupies the largest percentage with 73.0%, followed by branches with 12.8%, rhizome with 8.8% and the least in leaves with 5.4%).

1.2. Biomass and carbon stock Dendrocalamus barbatus Hsueh et D.A.Li forest

- The total fresh biomass of *Dendrocalamus barbatus* Hsueh et D.A.Li forest varies from 42.65 to 89.05 tons/ha with an average of 71.06 tons/ha. It is concentrated in the species layer (85.66%), its roots (7.72%), litter (4.88%), and ground vegetation (1.73%).

- The total dry biomass is about 21.65-44.87 tons/ha, averaging 35.95 tons/ha. 84.14% of the dry biomass is concentrated in *Dendrocalamus barbatus* Hsueh et D.A.Li layer, 7.88% in its roots, 6.56% in litter and 1.42% in ground vegetation.

- 11.09-20.54 tons/ha is the amount of carbon stock in *Dendrocalamus barbatus* Hsueh et D.A.Li forest. In which, the majority falls in the tree layer (accounting for 88.07%) and the minority is in ground vegetation with 1.11%. The roots and litter stay in the middle with 6.66% and 4.16%.

1.3. Biomass dynamics and carbon stock dymanics by individual tree age

- Biomass dynamics: The biomass of the age 2 plants increases from 1.05 to 1.13 times compared to which of age 1 trees. The same happens to the biomass of the trees at the age 3, which is 1.02-1.14 times higher than that of

the age 2 ones. A *Dendrocalamus barbatus* Hsueh et D.A.Li plant at the ages of 3 and 4 years has almost stable biomass.

- Carbon dynamics: The carbon stock is 1.08 - 1.13 times increased when the tree is at the age of 2. Similarly, the carbon sequestered in the tree at the age 3 rises 1.02-1.14 times compared to which of age 2. Trees at the ages of 3 and 4 have nearly unchanged carbon stock.

1.4. Biomass dynamics and carbon stock dymanics of Dendrocalamus barbatus Hsueh et D.A.Li forest

- Biomass dynamics: The total current and removed biomass of *Dendrocalamus barbatus* Hsueh et D.A.Li forest increases gradually with age. For instance, the total biomass of the forest age class II reaches 73.66 tons/ha, increasing to 125.01 tons/ha in the age class III (a rise by 1.7 times compared to the immediate previous age class). At age class IV, the total biomass increases by 2.32 times. The amount hits top when the forest is at age class VI with 17.1 times increased in comparison to that of age class II and 260.46 tons/ha obtained.

- Carbon stock dynamics: the total carbon stock at age class I is 16.21 tons/ha, which increases by 2.34 times at the age class II and 3.98 times when at the age class III. The amount of carbon gets the highest level when the forest is at age class VI with 134.15 tons/ha.

1.5. Development of allometric equations

- 12 allometric equations between fresh, dry biomass and the carbon stock in an individual plant and in forests of *Dendrocalamus barbatus* Hsueh et D.A.Li with the survey factors such as $D_{1,3}$, Hvn, Age (A) and forest density (N) have been developed in this research.

- In addition, two equations for biomass dynamics and carbon dynamics of *Dendrocalamus barbatus* Hsueh et D.A.Li forest with survey factors Age (A) and (N) have been formulated.

1.6. Proposed Solutions

- The dissertation provides specific solutions for sustainable management of *Dendrocalamus barbatus* Hsueh et D.A.Li forest to contribute to the

maintenance of carbon sinks in pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantations in Thanh Hoa province.

- A recommendation is made to use the average carbon stock ratio of its culm (72.34%, equivalent to a conversion coefficient of 1.38) to convert to the amount of carbon sequestered in the entire *Dendrocalamus barbatus* Hsueh et D.A.Li plant

2. Limitations

- Due to the time and fund limits, the amount of carbon sequestered in the forest soil as well as the site's effects on biomass and carbon stock of *Dendrocalamus barbatus* Hsueh et D.A.Li forest have not yet been studied.
- The research is carried out in only 4 districts where the Dendrocalamus barbatus Hsueh et D.A.Li is gathered and no data collection is made in other districts in the province.

3. Recommendations

- In order to have more scientific bases for the payment for forest environmental services for *Dendrocalamus barbatus* Hsueh et D.A.Li plantations, more researches should be implemented to determine the amount of carbon sequestered in *Dendrocalamus barbatus* Hsueh et D.A.Li forest soil as well as the post-harvest use of the bamboo species for different purposes.
- The research results can be used to calculate the value of carbon sequestration and storage services in ecosystem of the pure *Dendrocalamus barbatus* Hsueh et D.A.Li forest as the basis for the payment for environmental services. The biomass and carbon prediction equations may be applied to determine the biomass and carbon stock for pure *Dendrocalamus barbatus* Hsueh et D.A.Li plantations in Thanh Hoa province as well as in other areas where *Dendrocalamus barbatus* Hsueh et D.A.Li is distributed with similar ecological conditions.

LIST OF PUBLICATIONS

1. Nguyen D.H, Nguyen H.T. 2019."Study of biomass and carbon stock of *Dendrocalamus barbatus* Hsueh et D. Z. Li species in Thanh Hoa Province". *Vietnam Journal of Forest Science* No. 2/2019: 89-100.
2. Nguyen D.H, Nguyen H.T. 2020."Research on biomass and biomass dynamics of pure *Dendrocalamus barbatus* Hsueh et D. Z. Li plantations in Thanh Hoa Province". *Vietnam Journal of Forest Science* No. 1/2020: 46-61.