MINISTRY OF EDUCATION & TRAINING
MINISTRY OF AGRICULTURE & RURAL DEVELOPMENT
VIET NAM NATIONAL UNIVERSITY OF FORESTRY

KIEU THI DUONG

RESEARCH ON LIGHT REQUIREMENT OF *Castanopsis boisii* Hickel & A. Camus AT REGENERATION STAGE IN SOME NORTHEAST PROVINCES OF VIETNAM

Major: Silviculture
Code: 96 20 205

DISSERTATION SUMMARY
Supervisor: Prof. Dr. Vuong Van Quynh

Hanoi, 2018

THE DISSERTATION IS COMPLETED AT:

VIETNAM NATIONAL UNIVERSITY OF FORESTRY

Supervisor: Prof. Dr. Vuong Van Quynh

Reviewer 1:

Reviewer 2:

Reviewer 3:

The dissertation will be defended in front of the University Dissertation Examiner Council at Viet Nam National University of Forestry at …, on … 201...

It is possible to learn about the dissertation at: National Library, Library of Viet Nam National University of Forestry.

INTRODUCTION

1. Problem statement

Stretching from the Northern Center to the North Central Coast, the *Castanopsis boisii* forest naturally exists with thousands hectares concentrated mainly in Bac Giang, Hai Duong, Quang Ninh, Ninh Binh, Ha Tinh, and Quang Binh provinces.

C. boisii which is native species of Vietnam has high economic and ecological values.

According to statistics of the current status of forest and forestry land in 2017, Bac Giang has about 1,300 hectares and Hai Duong has 1,200 hectares of pure natural *C. boisii* forest (Bac Giang provincial People's Committee, 2017; Hai Duong Provincial FPD, 2017). Each year, one hectare of *C. boisii* forest gives about 1,500 to 3,500 kg of seeds. In 2017, the average selling price of 1 kg seed was 20,000 VND/kg. Therefore, the income from *C. boisii* forest is 30 -70 millions VND/ha /year.

Although the income is high, the restoration of *C. boisii* forest needs complicated technology and long time, so for many years the area of *C. boisii* forest has not increased. Based on the analysis of economic and environmental values, the government and local people are very eager to restore the *C. boisii* forest. In Bac Giang and Hai Duong provinces, the conservation and development of *C. boisii* forest is a top priority in many legal documents such as Resolution No. 101 - HDND (December 20, 2017), Resolution No.68-NQ/HU (March 24, 2016), Decision 29/2017-QD/UBND (August 24, 2017), Resolution of the Standing Committee of Bac Giang Provincial Party Committee No. 249 - NQ / TU (November 1, 2017)) etc.,

Addressing the actual requirements, this dissertation aims to fulfil the gap of ecological knowledge of *C. boisii*, especially at regeneration stage. The results of the dissertation show the characteristics of light requirements of regeneration *C. boisii* as a basis for effective solutions to restore *C. boisii* in Chi Linh (Hai Duong) and Luc Nam (Bac Giang). These two places were chosen for study site because they are the two largest localities of forest area and productivity in recently. The dissertation contributes to the protection and sustainable development of forest ecosystems in general and *C. boisii* forests in the research areas in particular

2. The research objectives

2.1. General objectives

Building scientific knowledge to develop *C. boissi* forest in Bac Giang and Hai Duong provinces.

2.2. Specific objectives

To determine light requirement of *C. boisii* in regeneration stages in Bac Giang and Hai Duong provinces.

To provide technique solutions base on research results about light requirement of regenerated *C. boisii* to developing *C. boisii* forest in research areas.

3. Scientific and practical significances

3.1. Scientific significance

- The thesis has determined the rule of changing the light requirements according to the height of the *C. boisii* regeneration. The light requirement of the regenerated tree is shown by the requirement of canopy closure and radiation intensity under the forest.
- The scientific value of the thesis is to improve awareness of the requirement of light of seedling *C. boisii.* This is the scientific basis for proposing technical measures to ensure the light requirement of regenerated *C. boisii* to restore and develop *C. boisii* forests in research areas.

3.2. Practical significance

The thesis has promoted the technical solutions to restore *C. boisii* forest through solving the requirement of lighting of regenerated *C. boisii* in the research areas.

4. New contributions of the dissertation

Theoretically: The thesis has determined the law of changing the light requirements according to the height of the regenerated *C. boisii* tree - a crucial ecological characteristic of regeneration trees. This is the basic knowledge and an important scientific basis for developing technical measures to restore and develop *C. boisii* forests in research areas.

Practically: The thesis has proposed a canopy closure table to look up the appropriate canopy value, the threshold of radiation intensity under the canopy suitable for each height levels of the regenerated *C. boisii.* This is the basis for proposing technical solutions to restore *C. boisii* forest through solving the requirement of lighting of seedling *C. boisii* in the research areas.

5. The object and scope of the research.

5.1. Research object

The object: *C. boisii* Hickel & A. Camus, 1921, at the regeneration stage distributed in Bac Giang and Hai Duong provinces. Regenerated tree is understood as a tree with a diameter at breast height of less than or equal to 6cm, a height of the top of the tree is below the main canopy of the forest.

5.2. Research scope

The thesis is conducted in two main locations: Luc Nam district, Bac Giang province and Chi Linh district, Hai Duong province - these are the two places with natural *C. boisii* forest distribution and the largest area currently. In this thesis, it will be called Chi Linh and Luc Nam when referring to the research sites.

The process of research collecting data is from 2014 to 2017.

The thesis focuses on research the light requirement of regenerated trees through the requirement of canopy closure. This is the factor closely related to the intensity and quality of radiation under the forest canopy and this factor is stable, easy to investigate, can be implemented on a large scale, regardless of the weather conditions at the time of the study. Besides the radiation intensity under the forest canopy and the microstructure characteristics of leaves as anatomical characteristics, chlorophyll content are also studied.

CHAPTER 1
LITERATURE REVIEW

1.1. Researches in the world

1.1.1. Researches on Fagacea family and *Castanopsis* genus in the world

1.1.2. Research on relationship between forest regeneration and forest characteristic.

1.1.3. Research on light requirement of forest tree and the changing of anatomy of the leaves

1.2. Researches in Viet Nam

1.2.1. **Researches on Fagacea family and *Castanopsis* genus in Vietnam**

1.2.2. Research on relationship between forest regeneration and forest characteristic

1.2.3. Research on light requirement of forest trees and the changing of anatomy of the leaves.

1.3. Some reviews and discussions.

Some of reviews and discussions are drawn as follows:

- The morphological anatomy characteristics are clearly related to the requirements and demands light of the regenerated trees.
- The canopy closure is a good indicator reflecting the light regime in the forest when studying requirement light of regenerated trees.
- The requirements and demands light of regenerated trees vary with each stage of growth of regenerated trees, according to age and according to the forest conditions.
- The forest canopy closure can be investigated by methods on systematic random points.
- The light requirement of regeneration trees is studied through the appropriate canopy closure with a great practical significance.

CHAPTER 2
RESEARCH CONTENTS AND METHODS

2.1. Research contents

2.1.1.Research on characteristics of micro conditions in *C. boisii* distribution areas.

2.1.2. Research on forest structure and regeneration characteristics of *C. boisii* forest in study areas.

2.1.3. Research on light requirement of regenerated *C. boisii*.

2.1.4. Research on finding solutions *C. boisii* rehabilitating in study areas.

2.2. Research methods

2.2.1. The opinion and approaches

2.2.1.1. The opinion

Forest regeneration in terms of economic is the process of reproducing and expanding forest resources, so to ensure the sustainable development of the *C. boisii* forest, researches on *C. boisii* regeneration are necessary.

Although *C. boisii* is a lightdemander plant completely in mature, but like many other native broad-leaved species, *C. boisii* requires a shade at regeneration stages at different levels. Studying the distribution characteristics of regenerated trees at different levels of height or age according to the canopy closure will clarify the light requirement of regenerated *C. boisii*. Because the anatomical structure of leaves is dependent on the characteristics of the lighting regime and the light requirement of the species, studies of the microstructure characteristics of *C. boisii* leaves in the laboratory will complement the results of light requirement of that species.

2.2.1.2. The approaches

- Systematical approache
- Experimental ecology approache -

Object-oriented approach in ecological research

2.2.2. Detail research methods

2.2.2.1. Methodology of survey transects determination

Using the regional forest status map, experience of local forestry officers, 23 survey transects were selected.

2.2.2.2. Regenerated tree investigation method

Along the survey transects, the whole of regenerated *C. boisii* is investigated – being trees that with a diameter of less than 6cm and within the width of 10 m of the transect. Investigated factors includes the height of the tree (H_{vn}, cm), the canopy diameter (D_t, cm), the stem diameter (D_o, mm).

2.2.2.3. Method of investigating high tree layer characteristics

In order to obtain data on high tree layer characteristics, the dissertation takes the position of regenerated *C. boisii* trees as a center to investigate 6 trees of the nearest high floor around. For each tree, measure H_{vn} (m), breast perimeter at 1.3m (C_{13}, cm), canopy diameter (D_t, m) and distance to regenerated *C. boisii* tree (L, m).

2.2.2.4. Canopy closure measurement method

The canopy closure was investigated for each seedling *C. boisii* tree. At the location of each seedling tree, a standard square of 100 m^2 is set up, investigating the canopy closure by the standard plots by 36 points.

2.2.2.5. The method to investigate the coverage of fresh carpet shrubs and dry carpets

The coverage of dry carpet and shrub vegetation at the location of each seedling tree is determined on the 4m^2 plots by determining the percentage of their cover area on the plots. Each regenerated tree on the transect is the center of a plot.

Investigating the names of fresh shrubs species and their average height in plots.

Table 2.1. Number of investigated samples by the thesis

Province	N_o. of transect	Aver. length of transect (m)	N_o. of investigated regeneration *C. boisii*	N_o. 100 m^2 standard plots	N_o. 4m^2 standard plots
Bac Giang	09	65	2264	148	309
Hai Duong	14	44	799	429	473
Total	23	1200	3063	577	782

2.2.2.6. Methods of investigating topographic factors

The geographic coordinates and absolute altitude at the location of each regenerated *C. boisii* tree are determined by the Garmin GPSMAP 60CSx GPS, the slope is determined by the handheld compass.

2.2.2.7. Methods of investigating soil characteristics

Soil characteristics are investigated through rapid measurement equipment, sampling and laboratory analysis tools. Includes: Soil thickness, density and porosity of soil, moisture, pH, mechanical composition, content of humus, easily digested nitrogen and phosphorus.

The laboratory analysis method is presented in detail according to the analysis process as follows:

Soil humus content is determined by titration method of $K_2Cr_2O_7$ in sulfuric acid according to Vietnam Standard 8941: 2011.

The content of easily digested phosphorus P (PO_4^{3-}) was determined by the Olsen method using $NaHCO_3$ solution according to Vietnam Standard 8661: 2011.

(NH_4^+) is determined by Nessler reagent method.

2.2.2.8. Methods of determining radiation under forest canopy.

At the location of each regenerated *C. boisii* tree, using Nikon Fisheyes converter FC-E8 to take pictures of the forest canopy. Then using Gap Light Analyzer (version 2.0) software (GLA 2.0) to interpret images. Interpretation results include: Open canopy (%), radiation intensity under canopy, ratio and intensity of direct and indirect radiation, %, Mol/m^2/day ....

Table 2.2. Number of analyzed soil, leaf, and photo samples

Province	N_o. transects	N_o. of investigated regeneration *C. boisii*	N_o. soil samples	N_o. leaf samples	N_o.photos samples
Bac Giang	09	2264	66	32	238
Hai Duong	14	799	34	22	145
Total	23	3063	100	54	383

2.2.2.9. Methods to studying chlorophyll content and anatomical characteristics of C. boisii leaves

- Collecting samples of regenerated *C. boisii* leaves at different height of seedlings and at different canopy closure.
- Collecting leaf samples of mature *C. boisii* trees - which are fully illuminated.
- At the same time, measuring the canopy closure of tall trees at leaf sampling locations.
- Analyzing the chlorophyll content by method of Benz et 1980. Measuring of optical density of extract at wavelengths of 663 nm and 645 nm on spectrophotometer SPECTRO 23RS, LABOMED firm.
- Using Optika M-699 microscopes microscopes with Optikam PRO 3 Digital Camera, with 150 times magnification to determine anatomy of *C. boisii* leaves.

2.2.2.10. Methods to determining the rules of regenerated C. boisii distribution

From the GPS coordinates of each regenerated *C. boisii* tree, ArcGIS 10.3 software is used to determine the rules of distribution of *C. boisii* in three forms: Clustered, Random and Scattered distribution. The algorithm of the Euclidean Distance in ArcGIS is used to determine the distribution characteristics of regenerated trees.

2.2.2.11. Data analysis methods

Using Excel, SpSS, ArcGIS, GLA software to synthesize and analysis data.

CHAPTER 3
RESULTS AND DISCUSSION

3.1. Characteristics of subatmospheric where *C. boisii* regenerates

3.1.1. Topographic characteristics

The results of elevation and slope of 3063 survey points on transects in the study areas are summarized as follows:

Table 3.1. Some topographic features of the *C. boisii* study areas

Location	Slope (º)				Attitudes (m)			
	N	TB	Std	V%	N	TB	Std	V%
Luc Nam	2264	20,2	1,85	9,2	2264	87,9	23,1	26,3
Chi Linh	799	23,2	4,6	19,6	799	82,9	31,9	38,6

In which N is the number of measured samples

In most of transects, *C. boisii* are distributed at attitude below 150m above sea and below 25^0slope.

The dissertation also statistics the number of regenerated trees at different altitudes, the results are shown in the following table.

Table 3.2. Distribution of number of regenerated *C. boisii* by attitude

OD	Attitudes (m)	No. of seedling *C. boisii*
1	< 50	209
2	50 - <100	2127
3	100 - <150	668
4	150 - < 200	58
5	200 - 250	1

The data shows that regenerated *C. boisii* is concentrated mainly at an altitude of 50m – 150m. This is a low mountain and hilly area, the results are consistent with previous studies (Dang Ngoc Anh, 1995; Nguyen Toan Thang).

- The slope: The statistics in above table show that the research transects are distributed on low slope areas. The average slope in the transects mainly ranges from 20 to 25 degrees. This is a place suitable for forest plantations, agro-forestry plantations, fruit gardens, etc. It is also convenient for forest caring and *C. boisii* harvesting.

3.1.2. The climatic conditions

The analytical results show that there is a high agreement on meteorological conditions in the study sites.

Thai Van Trung's drought index is calculated for both areas as follows: X = S.A.D. For both areas X is 5. Express X = 4.1.0 so in the *C. boisii* distribution areas has 4 dry months (11,1,2,3), 1 drought month (12) and no exhausting months.

3.1.3. Soil characteristics

Results of surveying soil characteristics are summarized in the following table:

Table 3.3. Some soil characteristics of the regenerated *C. boisii* research areas

Location	Investigation criteria							
	dA+dB (cm)	Soil porosity (%)	Soil moisture (%)	Soil thickness (mm)	pH	N - NH_4^+ (mg/100g)	P-PO_4^{3-} (ppm)	Humus content (%)
Luc Nam								
Mean	60,0	43,9	26,3	13,3	6,2	1,8	5,5	2,7
Max	94,3	48,0	58,0	20,0	6,8	4,0	10,4	7,2
Min	39,9	37,0	10,0	3,6	5,2	1,0	2,2	1,0
STD	12,9	2,6	5,1	3,3	0,2	0,6	1,6	0,8
V%	21,5	5,9	19,4	25,0	4,0	30,5	28,5	28,2
N_o	66	66	2278	2278	2278	66	34	34
Chi Linh								
Mean	49,0	43,8	21,3	16,2	6,2	2,8	6,9	3,2
Max	74,6	53	54,0	23,0	6,9	5,4	9,1	5,3
Min	33,0	32	8,0	7,5	5,6	0,7	4,8	2,1
STD	9,6	4,3	7,7	2,6	0,2	1,0	1,0	0,7
V%	19,7	9,9	36,1	15,8	4,0	36,1	15,0	22,6
N_o	34	66	785	785	785	34	34	34

Note: N_o is the number of the soil samples or the rapid soil samples.

The thesis has identified the relationship of soil porosity with the soil thickness shown in the equation as follows.

$$\mathbf{X = -0,7268*C + 54,59,\ R = 0,53} \qquad \mathbf{[3.1]}$$

In which: X- Soil porosity (%), C – Soil thickness (mm)

The assessments include medium humus content, low moisture, slightly acidic soil, poor digestible nitrogen, medium digest phosphorus.

The equation of relationship between surface soil moisture and the percentage of fresh carpet shrubs for the whole study areas as follows:

$$\mathbf{Y = 0,0549.\ X + 22,795,\quad R^2 = 0,74} \qquad \mathbf{[3.2]}$$

In which: X- the percentage of fresh carpet shrubs (%), Y – Soil moisture (%)

Research results show that when the coverage of fresh carpet shrubs changes from 10% to 90%, the soil moisture changes from 23% to 29%. Thus, when increasing the coverage under the forest can increase soil moisture up to 6%, the rest changes are due to other factors such as weather, slope, sun exposure, soil type etc.…

3.2. Structure and regeneration characteristics of *C. boisii* forests in the study areas

3.2.1. Structure characteristics and some forest stand elements

The upper layer density average in Bac Giang is 482 trees/ha, in Hai Duong is 558 trees/ha. The upper layer species composition includes: *Erythrophleum fordii, Liquidambar formosana, Ailanthus triphysa, Canarium album, Pinus latteri, ...* In which, the *C. boisii* accounts for over 90% of the species composition.

The upper layer species composition formula for Bac Giang is written as follows:

9,19 D + 0,213 K + 0,115 Lx + 0,16 S + 0,177 Tht + 0,144 Tr

The upper layer species composition formula for Hai Duong is written as follows:

9,79 D + 0,21 (Bs + Bln + K + Mr + Th + Tr)

Therefor the forest in the research areas can be considered to be the pure *C. boisii*

Table 3.8. The *C. boisii* forest inventory criteria in the research areas

OD	Inventory criteria	Luc Nam				Chi Linh			
		N_o	Mean	STD	V%	N_o	Mean	STD	V%
1	D_{13} (cm)	724	26,79	3,43	12,79	250	20,22	4,41	21,82
2	H_{vn} (m)	724	9,84	0,51	5,21	250	8,54	1,24	14,46
3	H_{dc} (m)	724	4,22	0,60	14,21	250	4,11	0,87	21,29
4	Dt(m)	724	4,17	0,39	9,33	250	3,65	0,41	11,27
5	TC	148	0,5	0,17	35	429	0,5	0,14	29
6	CP (%)	309	42	18,5	46,54	473	31,45	23,68	70,49
7	TK (%)	309	32,6	11,5	35	473	39,7	16,9	49,5
8	Hcb (m)	309	0,61	0,25	40,17	473	0,85	0,34	39,5

3.2.2. C. boisii regeneration characteristics

3.2.2.1. Some common characteristics of regenerated C. boisii

The regeneration characteristics results of *C. boisii* at Luc Nam and Chi Linh are shown in Appendix 09 and summarized in the following table.

Table 3.10. Some investigation characteristics of regeneration *C. boisii* in the research areas

Location	Regeneration density (trees/ha	Regeneration density with ≥ 1m (trees/ha	D_0 (cm)	Hvn (m)	Canopy diameter (Dt) (cm)	Proportion of potential regeneration *C. boisii* (%)
Luc Nam						
Mean	4215	2738	2,2	0,9	46,0	62,1
STD	3976	3042	1,2	0,2	47,3	14,1
V%	94	111	53,1	25,1	102,8	22,7
Chi Linh						
Mean	1563	317	1,6	0,6	52,6	25,3
STD	1297	152	0,6	0,2	15,9	27,1
V%	83	48	37,8	35,9	30,2	107,2

The regenerated *C. boisii* density average in Chi Linh is 1563 trees/ha lower than that in Luc Nam (4215 trees/ha). The very large density variation in the transects shows that the coefficient of variation is over 80% in both areas. The density of seedling *C. boisii* with ≥ 1m average in Chi Linh is 317 trees/ha, in Luc Nam is 2738 trees/ha. Comparing with the density of economic species over 1 m (Pham Van Dien, Pham Xuan Hoan, 2016), the density of regenerated *C. boisii* in Luc Nam is satisfactory and in Chi Linh is slightly lower.

C.boisii height varies according to diameter with logarithmic function. The relationship between height and diameter of regenerated *C. boisii* is shown in the equation following:

$$Y = 0{,}636.\ Ln(X) + 0{,}4068 \qquad \textbf{[3.3]}$$

The proportion of potential regenerated *C. boisii* (those with a height greater than the average height of the fresh carpet shrub (Vu Tien Hinh, 2012)) average is 25.3% - 62%, if it is considered the regenerated tree is more than 1m in height, the average number of regenerated *C. boisii* for entire research areas is 40%.

3.2.2.2. The distribution pattern of regenerated C. boisii on the ground

Using the Euclidean distance function of ArcGIS software version 10.3, the thesis has identified the distribution characteristics of regenerated *C. boisii* for each transect. Summary of results as follows:

Table 3.11. Distribution characteristics of seedling *C. boisii* in the areas

Distribution pattern	Luc Nam	Chi Linh	Total
Dispersed distribution	0	03	03
Random distribution	0	01	01
Clustered distribution	8	10	18

Test results in the transects shows that the distribution pattern of regenerated *C. boisii* is mainly in clusters style (18 transects), there are 3 transects of Dispersed distribution, 1 transect of Random distribution. Random and Dispersed distribution styles are all related to relatively uniform of site conditions or having impacted human.

The data shows that the number of regenerated *C. boisii* is unevenly by distance to the nearest mother tree. The trend is that the number of regenerated *C. boisii* increases gradually from close to the mother tree to about 4 m, then gradually decreases and almost have no seedling trees in about 11 m from the mother tree.

It can be seen that the regenerated *C. boisii* distribution depends on the mother trees distribution. Almost seedling *C. boisii* are near the mother tree. From 8 m to 10 m, there is almost no regenerated tree. Therefore, the cause of cluster distribution of regenerated *C. boisii* is mainly related to the mother tree distribution. Each mother tree or a cluster of mother form a cluster distribution of regenerated trees.

3.2.2.3. The regenerated C. boisii trees number distribution according to the height level

The results of regenerated *C. boisii* distribution according to the height level for the whole research areas shows that: The seedling *C. boisii* number decreases fastest at the height of 0.6 m to 1.0 m. This is possible a transition phase from low light requirements period to high ones and strong competition not only nutrient on the surface but also underground.

The number of regenerated *C. boisii* is low at height below 0.4 m relating to the numerous cycle of *C. boisii*. After less fruit two years, it will have a numerous fruit year (Nguyen Khanh Xuan, 2006).

3.2.2.4. Distribution of regenerated C. boisii according to the coverage of fresh shrubs

The coverage of shrubs and fresh carpets greatly affects germination, survival and growth of regenerated trees. Summarizing the results of the distribution of regenerated *C. boisii* according to the coverage of fresh carpet and shrubs shows

The seedling *C. boisii* mainly distributed in where having 25% -50% covering fresh shrubs and carpet. To promote regenerated of *C. boisii*, it should maintain the coverage of fresh carpet shrub at less than 50%.

3.2.2.5. Regenerated C. boisii distribution according to the slope

There is different seedling *C. boisii* distribution in different slopes. It rarely have regenerated *C. boisii* at below 10^0 or above 25^0. They are distributed much at a slope of 10^0 to 25^0.

3.3. The light requirement of *C. boisii* in the research areas

3.3.1. The relationship between canopy closure and radiation intensity under the C. boisii canopy.

Radiation intensity under canopy depends on forest canopy closure. Radiation results under forest according canopy closure as follows:

Table 3.15. Radiation characteristics under the canopy of *C. boisii* forest at different canopy levels.

Canopy closure	Radiation under canopy – RC (%)	Radiation intensity under canopy (KWh/m^2.day)					N_o. of analysis photos.
		Mean	Min	Max	Std	V%	
0,0-0,1	41,5	0,74	0,74	0,74	0,0	0,0	1
0,1-0,2	32,62	0,58	0,52	0,69	0,05	9,08	23
0,2-0,3	28,4	0,51	0,49	0,52	0,01	1,95	24
0,3-0,4	24,02	0,43	0,38	0,49	0,03	7,81	174
0,4-0,5	19,27	0,34	0,3	0,38	0,02	6,57	74
0,5-0,6	12,98	0,23	0,12	0,3	0,05	21,90	47
0,6-0,7	4,85	0,09	0,08	0,1	0,01	9,67	5
0,7-0,8	3,53	0,06	0,06	0,06	0,0	0,0	1
Aver/Total	**20,9**	**0,37**			**0,02**	**7,12**	**349**

The table shows that radiation under canopy about 3.53% to 41.5%, an average of 20.9% compared to the total amount of light reaching the forest canopy. Corresponding radiation intensity under the canopy of 0.06 to 0.74 KWh /m^2.day and an average of 0.37 KWh/m^2.day. Compared with the average radiation intensity for the Northeast of Vietnam is 3.1 - 3.8 Kwh/m^2.day (Vuong Van Quynh, Tran Tuyet Hang, 1999, Vu Phong, 2018), the amount of radiation of research area is slightly low.

The relationship between canopy closure and radiation under the forest of 349 regenerated *C. boisii* are as follow:

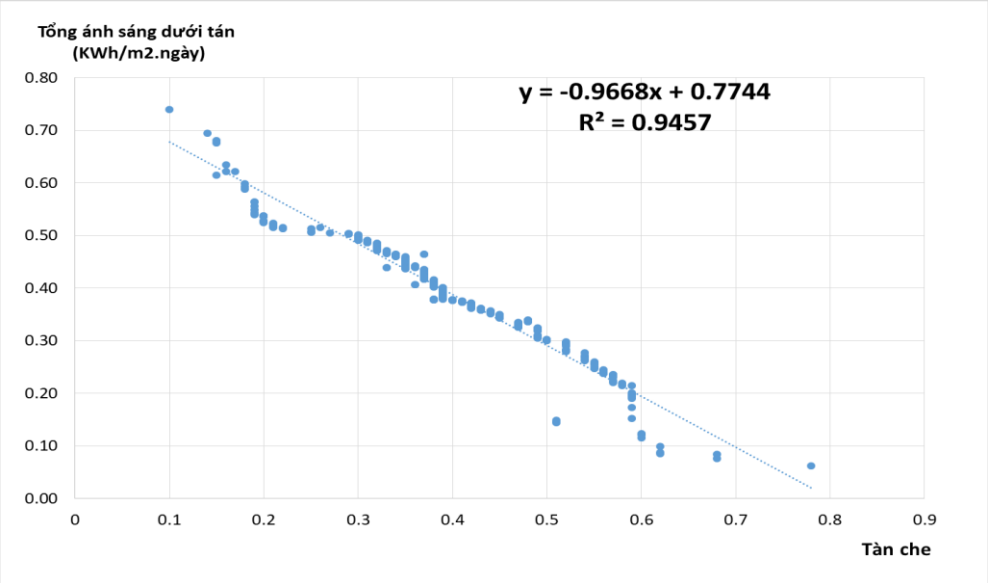

Figure 3.30. The relationship between canopy closure and radiation intensity under the forest

The equation is as follows

$$\mathbf{Y = - 0{,}9668 \,.\, X + 0{,}7744;\ R^2 = 0.94} \qquad \mathbf{[3.4]}$$

In which, Y is radiation intensity under the forest (kWh/m^2.day)

X is canopy closure.

The error of the equation is 15.9%. With this error, the equation [3.4] can be used to interpolate the amount of radiation under the forest when we know canopy closure.

3.3.2. The light requirement of the regenerated C. boisii

The number of seedling *C. boisii* according to the canopy closure is as follows.

Table 3.16. Distribution of regenerated *C. boisii* trees according to the canopy closure

OD	Canopy closure	N_o. Regenerated *C. boisii*	Percentage (%)
1	< 0,2	187	6
2	0,2 - 0,4	798	26
3	0,4 – 0,6	1289	42
4	0,6 – 0,8	546	18
5	> 0,8	243	8
Total		3063	100

Characteristics of regenerated *C. boisii* distribution at different heights according to the canopy closure

Table 3.18. Distribution of number of regenerated *C. boisii* trees according to canopy closure and height

OD	Canopy closure	Regenerated *C. boisii* height (m)				Total N_o. regenerated *C. boisii*
		≤ 0,4	0,4 - ≤ 0,8	0,8 - ≤ 1,2	> 1,2	
1	0,05 - 0,1	0	0	0	3	3
2	0,1 - 0,2	6	30	0	148	184
3	0,2 - 0,3	33	59	23	3	118
4	0,3 - 0,4	63	306	211	100	680
5	0,4 - 0,5	106	408	156	34	704
6	0,5 - 0,6	93	324	143	63	623
7	0,6 - 0,7	163	119	72	37	391
8	0,7 - 0,8	95	70	5	12	182
9	0,8 - 0,9	148	9	21	0	178
10	0,9 - 1,0	0	0	0	0	0
Total		707	1325	631	400	3063

In order to determine the light requirement of regenerated *C. boisii* at different heights, the thesis has based on the data in the above table to build the chart and relationship style. The common form of charts is the curve with vertices. Using SPSS software, the thesis has identified the key indicators of the regenerated *C. boisii* distribution as follows.

Table 3.20. Distribution characteristics of regenerated *C. boisii* according to the canopy closure at the difference height

Regenerated *C. boisii* height level (m)	Key indicators				Distribution pattern	Peak of distribution	Range of distribution (70% N_o. regenerated *C. boisii*)
	Mean	Median	Mode	Skewness-			
≤ 0,4	0,61	0,65	0,75	- 0,36	Right deviation	0,80	0,6 - 0,9
0,4 - ≤ 0,8	0,47	0,45	0,45	0,19	Near symmetry	0,45	0,3 – 0,55
0,8 - ≤ 1,2	0,47	0,40	0,35	0,79	Left deviation	0,35	0,2 – 0,5
>1,2	0,35	0,30	0,20	0,34	Left deviation	0,20	0,1 - 0,4

Analyzing the data shows the distribution peak that is the canopy closure where has maximum distribution regenerated *C. boisii* (TCm) that changes according to *C. boisii* height. The higher the tree, the lower canopy closure in the peak distribution.

If the peak distribution of regenerated *C. boisii* is considered the suitable canopy closure and the distribution range of 70% of seedling trees are the suitable canopy closure range, upper threshold (TCt) and lower threshold (TCd) of this range as shown Figure below.

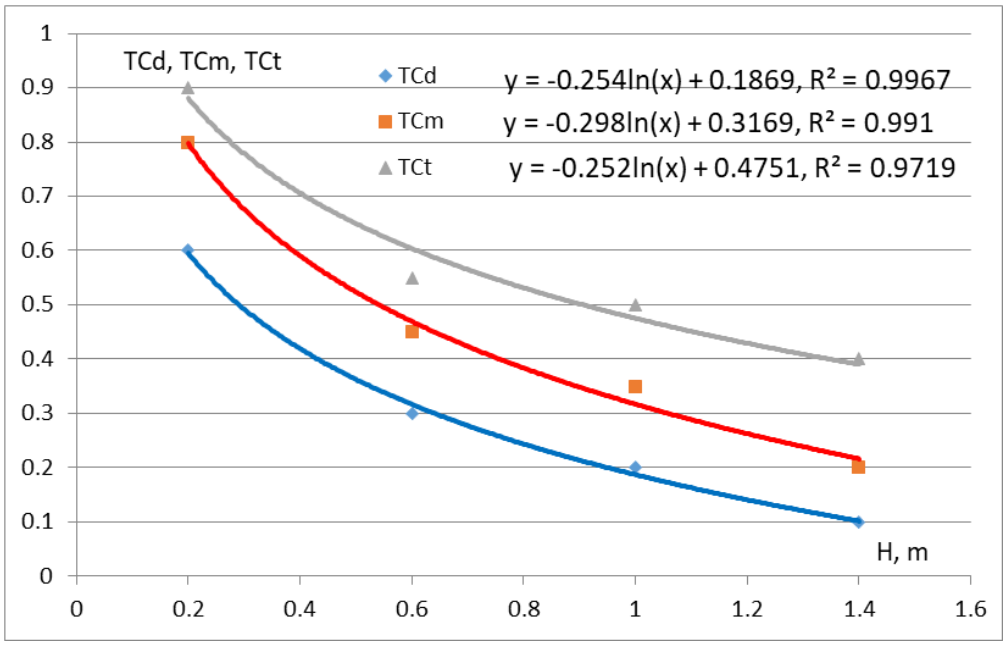

Figure 3.38. Changing of suitable canopy closure thresholds for regenerated *C. boisii*

(The most appropriate canopy closure -TCm, below threshold –TCd and upper threshold -TCt of suitable canopy closure range).

The distribution of appropriate canopy closure, the lower and upper suitable thresholds of the canopy closure with height regenerated *C. boisii* all has a gradual reduction of logarithmic curves. Experimental equations as follows.

$$TCm = - 0.298. \ln(H) + 0{,}3169, R^2 = 0{,}99 \quad \textbf{[3.5]}$$

$$TCd = - 0{,}254l. n(H) + 0{,}1869, R^2 = 0{,}99 \quad \textbf{[3.6]}$$

$$TCt = - 0.252. \ln(H) + 0{,}4751, R^2 = 0{,}97 \quad \textbf{[3.7]}$$

In which H is height of regenerated *C. boisii* (m).

Using the above equations to build a table to determine the suitable canopy closure for regenerated *C. boisii* according to their height.

From the equation [3.4] (between canopy closure and radiation intensity). it is possible to determine the suitable radiation intensity under the forest of *C. boisii* according to their height as follows:

Table 3.21. The suitable canopy closure and radiation intensity to regenerated *C. boisii* at different heights

OD	H (m)	Suitable canopy closure			Suitable radiation intensity -I (KWh/m^2.day)		
		TC_m	TC_d	TC_t	$I_{optical}$	I_{below}	I_{upper}
1	0,20	0,76	0,60	0,88	0,04	0,01	0,19
2	0,30	0,66	0,49	0,78	0,14	0,02	0,30
3	0,40	0,60	0,42	0,71	0,19	0,09	0,37
4	0,50	0,54	0,36	0,65	0,25	0,15	0,43
5	0,60	0,50	0,32	0,60	0,29	0,19	0,47
6	**0,80**	**0,43**	**0,24**	**0,53**	**0,36**	**0,26**	**0,54**
7	**1,00**	**0,38**	**0,19**	**0,48**	**0,41**	**0,31**	**0,59**
8	1,20	0,34	0,14	0,43	0,45	0,36	0,64
9	1,60	0,27	0,07	0,36	0,51	0,43	0,71
10	2,00	0,22	0,01	0,30	0,56	0,48	0,76
11	2,40	0,18	0,00	0,25	0,60	0,53	0,77
12	2,80	0,14	0,00	0,22	0,64	0,56	0,77
13	3,20	0,11	0,00	0,18	0,67	0,60	0,77
14	3,60	0,08	0,00	0,15	0,70	0,63	0,77
15	4,00	0,06	0,00	0,13	0,72	0,65	0,77

The results show that there are different requirements canopy closure of regenerated *C. boisii*. The higher the height of regenerated trees, the more light required, the lower forest canopy closure. The data also proves that *C. boisii* is a shade tolerant species in the regeneration stage but growing up this is actually a strong light requirement tree. At a height of 3 m, the regenerated tree requires a canopy closure less than 0.2. The illumination is almost complete.

The regenerated *C. boisii* of 0.8 m when converted into a potential regenerated tree with a height of over 1 m, the average appropriate radiation intensity under the forest canopy increases from 0.36 KWh./m^2.day to 0.41 KWh./m^2.day, the most appropriate canopy closure decreased from 0.43 to 0.38. Accordingly, the appropriate radiation threshold also changes.

3.3.3. Canopy closure requirement of regenerated C. boisii in relation to some site factors

Establishing the relationship between canopy closure and some site factors with the height of regeneration trees to clarify the regeneration *C. boisii* light requirements in relation to other factors. The site elements as slope (^{0}), absolute elevation (m); humus content; thickness of soil layer (cm); Soil porosity (%)… all having an effect but it is insignificant to the light requirement of the regeneration *C. boisii* tree.

3.3.4. The effect of canopy closure to the anatomical characteristics and chlorophyll content of the regenerated C. boisii

3.3.4.1. Chlorophyll content of C. boisii leaves

(1) Chlorophyll content of regenerated *C. boisii* leaves

The chlorophyll content of the regenerated *C. boisii* in Bac Giang and Hai Duong are shown in Appendix 16 and summarized in the following table.

Table 3.24. Chlorophyll content of regenerated *C. boisii* in research areas

Index	Canopy closure at the leaf sampling site	Chlo a (mg/g)	Chlo b (mg/g)	Chlo (a+b) (mg/g)	Chlo a/b
Mean	0,43	1,57	0,82	2,4	1,98
Max	0,8	2,07	1,22	3,28	2,7
Min	0,1	1,01	0,43	1,45	1,53
STD	0,2	0,29	0,23	0,5	0,31
V%	49,6	18,1	27,8	20,9	15,5
N_o	41	41	41	41	41

In which N_o is a number of sample leaves

The data shows that the average chlorophyll content of regenerated *C. boisii* is 2,4 mg/gram and the ratio of chlorophyll a/b is 1,98. Compared to the total chlorophyll content and the ratio of chlorophyll a/b of broad-leaved plants, regenerated *C. boisii* is a shade-tolerant plant.

The analyzing results the chlorophyll content according to the sampling height show that the higher up, the more light the leaf receives, the lower the chlorophyll a and b content. However, from a height above 1,5 m, the chlorophyll a, b content tends to increase. The variation coefficient is big from 15% to 31%, especially for chlorophyll content b, variation coefficient is higher than other indicators.

The graphs show the change of chlorophyll content a, b and the ratio of chlorophyll a/b according to the canopy closure as follows:

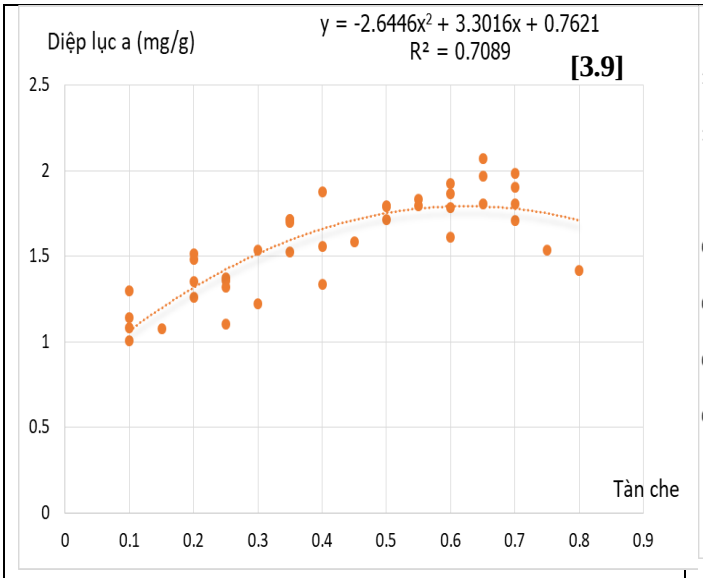

Figure 3.43. Relationship between Chlo a of seedling *C. boisii* to canopy closure

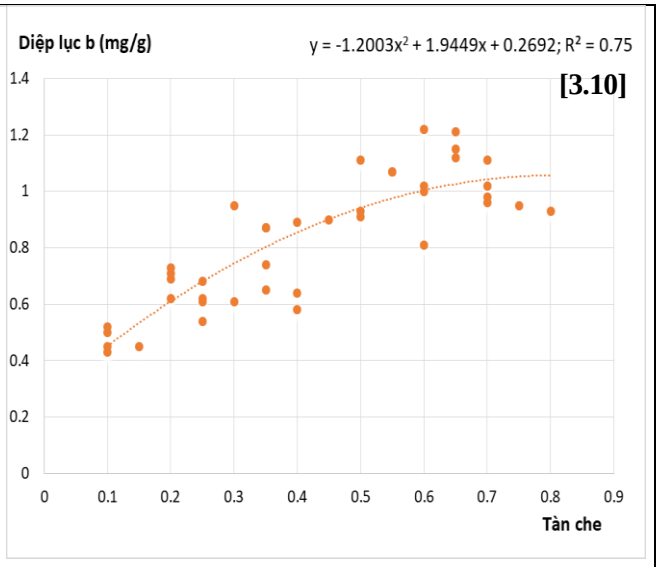

Figure 3.44. Relationship between Chlo b of seedling *C. boisii* to canopy closure

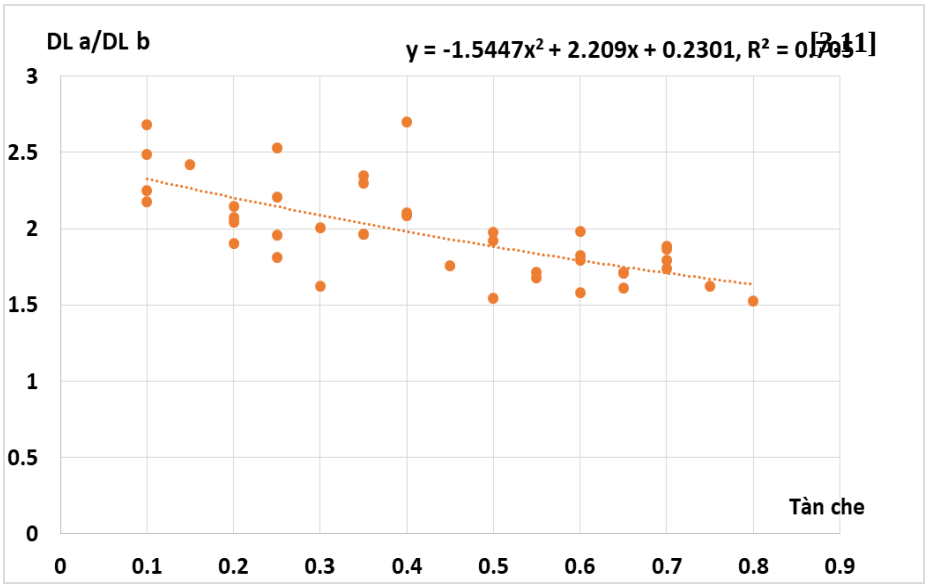

Figure 3.45. Relationship between Chlo a/b of seedling *C. boisii* to canopy closure

The higher the canopy, the lower the chlorophyll content. This shows that the less light the plants received, the higher the chlorophyll a and b. To a certain threshold corresponding to 0,7 and more of the canopy closure, the chlorophyll does not increase anymore and tends to decrease. Thus, regenerated *C. boisii* can adjust chlorophyll content to adapt to shade conditions. However, with most of the regenerated *C. boisii* when the canopy closure exceeds 0.7, it is no longer possible to increase chlorophyll content and the shade begins to negatively

affect their growth. Therefore, to promote regenerated *C. boisii* under the forest, it should maintain the maximum 0.7canopy closure.

The chlorophyll content of *C. boisii* leaves is lower than that of *Pterocarpus macrocarpus* and higher than that of *Endospermum chinense*.

Analyzing results of the Chlorophyll a,b content of mature *C. boisii* in fully light conditions listed in the following table.

Table 3.26. Chlorophyll content of mature *C. boisii*

Index	Chl a (mg/g)	Chl b (mg/g)	Chl a+ b (mg/g)	Chl a/b
Mean	1,29	0,45	1,74	2,90
STD	0,29	0,12	0,41	2,42
V%	29	26,1	55,1	1,11
N_o	13	13	13	13

Using standard U of Mann Whitney to compare chlorophyll content in regenerated mature *C. boisii* leaves shows that all comparisons have P value of less than 0,05. This shows that there is a statistically significant difference. Whereby the chlorophyll content of mature *C. boisii* is lower, Chlo a/b is higher than that of the regenerated *C. boisii* under the forest canopy.

3.3.4.2. Leaf anatomy of C. boisii

(1) The anatomy of regenerated *C. boisii* leaves

The results of anatomical analysis of the regenerated *C. boisii* leaves are shown in Appendix 17 and summarized in the following table:

Table 3.27. Anatomy structure of regenerated *C. boisii* leaves in research areas

Index	Thickness of leaf structure layers (µm)							Palis/Spongy
	Thickness of leaf	Upper Cuticle	Upper epidemis	Palisade parenchyma	Spongy parenchyma	Lower epidemis	Lower Cuticle	
Mean	150	2,5	8	45,2	86,2	6,34	1,82	0,54
STD	12,9	0,5	1,8	9,4	10,9	1,44	0,29	0,14
V%	8,6	21,2	22,4	20,8	12,7	22,7	16,0	25,9
N_o	41	41	41	41	41	41	41	41

In which N_o is a number of sampling analysis

From the data in the appendix and above table, it is shown that most of the anatomy criteria of regenerated *C. boisii* are changed according to the canopy closure. The thickness of the cutin layer and the epidermis ranges from 10,1 µm to 28,3 µm, accounting for 8,2% - 15,2% of the total thickness of the leaves. The thickness of palisade parenchyma from 24 µm - 59 µm, spongy parenchyma from 71µm - 110 µm, total anabolic tissues account for 77% - 91% of leaf thickness. The ratio of palisade /spongy parenchyma of regenerated *C. boisii* is 0.54 higher than this rate of *Endospermum chinense* (0.41), lower than that of *Aphanamixis grandiflora* (0.77), *Pterospermum diversifolium* (0.72) and *Clerodendron fragrans* (0.55) (Nguyen Thi Tho, Vu Quang Nam, 2013).

From the data, some the relationship between anatomy and the canopy closure graphs are built as follows:

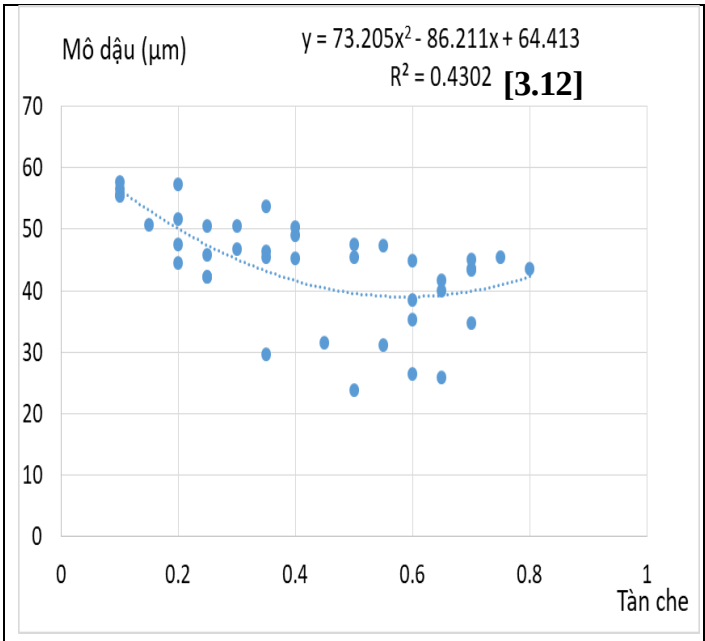

Figure 3.46. The relationship between the palisade parenchyma and canopy closure

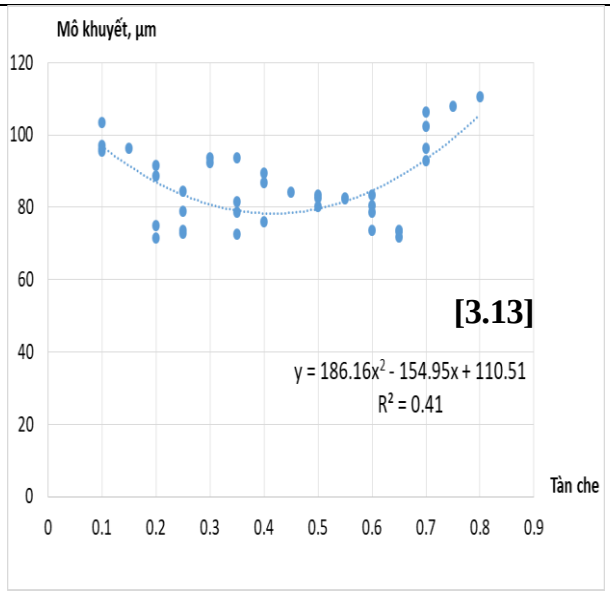

Figure 3.47. The relationship between the spongy parenchyma and canopy closure

In general, the thickness of anabolic tissue tends to decrease when the canopy closure increases to 0.7 then stabilizes or slightly decreases. This clearly shows that the canopy closure is considered a factor to adjust the leaf anatomical and the maximum tolerable threshold of regenerated *C. boisii* at 0.7 corresponds to the light intensity under the forest 0.1 KWh/m^2.day.

(2) The leaf anatomy of mature *C. boisii*

To compare the leaf anatomy of mature *C. boisii* with of regenerated *C. boisii*, some leaf samples of the mature tree have been analyzed, the results are as follows.

Table 3.28. Leaf anatomy of mature *C. boisii* - in fully light conditions

Index	Upper Cuticle (µm)	Upper epidemis (µm)	Palisade parenchyma (µm)	Spongy parenchyma (µm)	Lower epidemis (µm)	Lower Cuticle (µm)	Palis/ Spongy	Thickness of leaf (µm)
Mean	2,9	6,4	88	94,6	5	1,8	0,9	198,6
Std	0,5	0,9	19,0	12,6	0,7	0,3	0,2	27,4
V%	16,0	13,5	21,5	13,3	13,6	16,5	18,4	13,8
N_o	13	13	13	13	13	13	13	13

Similarly, using the U standard of Mann &Whitney to compare the differences between the leaf anatomy of the regenerated *C. boisii* and of mature ones.

Mature *C. boisii* that lives in full lighting conditions have had significant anatomical changes. In particular, the leaf thickness increases significantly, the leaf thickness increasing was mainly due to the strong increase of palisade parenchyma (from 45.2 µm to 88 µm) while the spongy tissue was not significantly increased. Therefore, the ratio of palisade/spongy increases from 0.54 to 0.9.

3.4. Solutions for restoring *C. boisii* forest in the research areas.

Based on the research results of the dissertation, some solutions for restoring *C. boisii* forest in research areas are proposed as follows:

3.4.1. Adjust the canopy closure to promote regenerated C. boisii under canopy

Adjusting the canopy closure is a good solution to promote the growth of seedling trees. In actual, we use the following table:

Table 3.30. Application canopy closure in practice to promote *C. boisii* regenerating

TT	Height of regenerated *C. boisii* (H, m)	Suitable canopy closure range	Suitable canopy closure
1	0,20	0,6 - 0,88	0,70
2	0,30	0,49 - 0,78	0,70
3	0,40	0,42 - 0,71	0,70
4	0,50	0,36 - 0,65	0,50
5	0,60	0,32 - 0,60	0,50
6	0,80	0,24 - 0,53	0,50
7	1,00	0,19 - 0,48	0,40
8	1,20	0,14 - 0,43	0,40
9	1,60	0,07 - 0,36	0,40
10	2,00	0,01 - 0,30	0,40
11	2,40	0 - 0,25	0,40

3.4.2. Adjust the canopy closure in the process of converting other forests into C. boisii forests

Gradually transforming from other forests (Acacia, Eucalyptus, Litchi, etc.,) into *C. boisii* forest, applying the rule of adjusting the canopy closure by thinning the forest following the above canopy closure table. Do not cut all other forests one times to restore the *C. boisii* forest. The solution is proposed for each type of object such as for the forest that having available seed sources or for the forests that have no or be far from natural seed sources.

3.4.3. Adjust the density to create evenly distribution of regenerated C. boisii on the ground

Results of analyzing the rule of regenerated *C. boisii* distribution showed that in the research areas, the distribution of regenerated *C. boisii* is uneven, mainly the cluster distribution. The main reason is related to the distribution of mother trees, not due to site conditions or biological group characteristics. Therefore, in places far from mother trees often has low regeneration density or no regeneration. Thus to making evenly distribution, it is possible to lift seedlings from a place with high density (often in places with many mother trees) to a low density place. Depending on the canopy closure at the transfer site, select regenerated trees with appropriate height. Normally, it is recommended to uproot trees with a height of more than 0.6m, which have higher survival.

The results of the thesis also show that the places where has the potential regenerated *C. boisii* (1m or more height). If having ensure density and evenly distribution, there is no need to move the regenerated trees from other places.

CONCLUSIONS

4.. Conclusions

Some conclusions are as follows

4.1.1. Characteristics of subatmospheric where *C. boisii* regenerates

By analyzing and comparing the topography, climate and soil characteristics in the Chi Linh and Luc Nam shows that: Although there is difference in ecological geography (according to the current division), there is no significant difference in site conditions. On the high belts, the *C. boisii* is distributes mainly at an altitude of less than 150 m above sea level and below 25^{o} the slope. The moist heat regime is high similarity via Thai Van Trung's drought index (dry and drought 5 months in a year).

Soil characteristics are assessed by the following criteria: porosity, humus content, easily digestible Phosphorus and Nitrogen, tightness, thickness of soil layer etc., indicators be evaluated from poor to medium level. The average humus content of Bac Giang is 2.7%, in Hai Duong is 3.2%. The average porosity is approximately 44%. The easily digested Nitrogen is from 1.3 mg/100g - 4.2 mg/100g, average 2.4 mg/100g. The easily digested phosphorus is from 2.8 ppm - 9 ppm, an average of 6.4 ppm, the soil pH average is 6.2, the soil is slightly acidic etc.,

4.2. Structure and regeneration characteristics of *C. boisii* forests in the research areas

The thesis has generalized the structure of *C. boisii* forest through some basic indicators such as density, canopy closure, coverage of fresh carpet shrubs and some forest stand survey factors. This shows that the average density of upper layer trees in Luc Nam is 482 trees ha, Chi Linh has a higher average density (558 trees/ha), with 6-7 species participating in the composition formula. Forest inventory indicators such as D1.3, Hvn, Dt, Hdc in Luc Nam are generally higher than in Chi Linh.

The thesis also determined the potential regeneration density and ratio of potential regenerated *C. boisii* from 40% - 62% of the total number of surveyed trees. At the same time, the dissertation has identified the distribution styles of regenerated *C. boisii* on the ground, mostly is the cluster distribution. The number of seedling *C. boisii* reduces rapidly at a height of 0,6 m-1 m etc.,

The structure forest results and stand indicators are important research results that decide the light under the forest and being meaningful for studying the light requirement of the regenerated *C. boisii*.

4.3. The light requirement of *C. boisii* in the research areas

The thesis has determined the relationship between radiation intensity under the forest and canopy closure through equation: Y = 0.7744 - 0.9668 TC. The result showed that the light under the forest accounted for an average of 21% of the total radiation reaches the surface corresponding to 0.37 KWh/m^2.day

Experimental equations reflect the most appropriate closure (TCm), lower threshold (TCd) and upper threshold (TCt) of the appropriate canopy closure range according to the height of regenerated trees (H, m) determined respectively follows.

$$TCm = - 0{,}298.\ln(H) + 0{,}3169, R^2 = 0{,}99$$

$$TCd = - 0{,}254.\ln(H) + 0{,}1869, R^2 = 0{,}99$$

$$TCt = - 0{,}252.\ln(H) + 0{,}4751, R^2 = 0{,}97$$

Based on the above equations, the appropriate canopy closure table for regenerated *C. boisii* was built.

In addition, the dissertation has determined the canopy closure requirement of regenerated *C. boisii* in relation to some site factors. The results show that site factors have a small effect on the light requirement of seedling trees.

The relationship equations and diagrams between chlorophyll a, b, chlo a/b ratio, the palisade/spongy ratio and the canopy closure were established. Mainly expressed by linear equations with a high determination coefficient (R^2). This result partly reflects the light requirements of regenerated *C. boisii*.

4.4. Solutions for restoring *C. boisii* forest in the research areas.

Based on the research results, some solutions for rehabilitating *C. boisii* forest in the research areas are suggested . Technical solutions are the key to solve the light requirement of regenerated trees, supporting the growth of seedling trees. These solutions are based on the ecological requirements of the species, contributing a scientific basis to rehabilitate *C. boisii* forest.

4.2. Limitation

- The research has not be able to cover all distribution areas of *C. boisii* in Vietnam leading to the result is limited to applicable for the study areas.

- The research has not manageble to verify and test the proposed solutions to check the feasibility of the solution.

- The research focused on only method of light determining of canopy closure requirement and radiation intensity rather than testing others such as determining through photosynthesis photon density index of plants, method of determining effective optical radiation, laboratory layout methods in different light modes ...etc

- The research is not able to clarify how the origin of regeneration could influence to the *C. boisii* light requirement .

- The study did not investigate some impacts of human activities on *C. boisii* regeneration that may have, although the researcher great cared about this issue as sites sellected where has the least affected human activities,.

4.3. Recommendations

Following the limitations, some recommendations are proposed as follows:

Expanding the study of the distribution area of *C. boisii* to diversify different forest status.

Continuing research to clarify how the regeneration origin affects the growth and the light requirement of seedling *C. boisii*.

Testing the feasibility of the proposed solutions to rehibilitate *C. boisii* forests for the research areas, and then apply the solutions to other distribution areas of the species.

List of publications

1. Kieu Thi Duong, Vuong Van Quynh, Dang Dinh Chat (2017), *Research on characteristics of the regenerated C. boisii trees (C. boisii Hickel et A . Camus) in Bac Giang and Hai Duong province*. Science and technology Journal of Agriculture and Rural development, N_o 6-2017, Pages.170-177.

2. Kieu Thi Duong, Vuong Van Quynh, Nguyen Viet Hung (2017), *Sunlight need of C. boisii species (C. boisii Hickel et A . Camus) at the regenerating stage in Luc Nam, Bac Giang*. Science and technology Journal of Agriculture and Rural development, N_o. 7-2017, Page:134-141.

3. Duong Kieu Thi, Quynh Vuong Van, Tho Nguyen Thi, Viet Hung Nguyen (2017), *Effect of canopy closure on chlorophyll content and anatomy structure of C. boisii leaves in the regeneration stage in Bac Giang and Hai Duong, Vietnam,* Journal of Forestry Science and Technology, No.2-2017, Page: 75-86