

**Ministry of Agriculture and Rural Development (MARD)**

**Forestry University – Tay Nguyen University**

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**Summary of Master's Thesis**

**FORECASTING CO<sub>2</sub> ABSORBILITY  
CAPACITY ON NATURAL BROAD-LEAVED  
EVERGREEN FORESTS IN TUY DUC DISTRICT,  
DAKNONG PROVINCE**

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**Granted by SEANAFE/ICRAF/SIDA**

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## **RESEARCH RATIONALE**

The increase of carbonic (CO<sub>2</sub>) in the atmosphere is becoming a global concern. In practice, the amount of CO<sub>2</sub> absorptivity depends on forest type, forest status, dominant tree species and forest stand age. Therefore, the researches about CO<sub>2</sub> absorptivity of each specific vegetation type are required to establish quantization for economic values of forest and build payment mechanism for environmental services.

It is the thesis which has lacked many researches in Vietnam.

In order to contribute to solving the above-mentioned thesis, a research on this issue was carried out “*Forecasting CO<sub>2</sub> absorptivity capacity on natural broad-leaved evergreen forests in Tuy Duc district, DakNong province*”

### **CHAPTER 1: LITERATURE REVIEW**

The author has overviewed documents, research results as well as international and national problems related to the research contents of the thesis accordant to the following domains : i) Global Climate System and CO<sub>2</sub> fluctuation in atmosphere; ii) Carbon sequestration in Eco-Systems and Researches about CO<sub>2</sub> fluctuation definition methods in vegetation; iii) Kyoto Protocol and implementing Potentialities in Vietnam.

Quick view to research results on problems related to CO<sub>2</sub> and international and national carbon market, it is remarked as follows:

- Quantification for the amount of CO<sub>2</sub> absorbed by forests is a complex problem, which is allied to photosynthesis and respiration process in vegetation as well as increment definition and elimination of forest trees chronologically.
- In some recent years, there have been researches on CO<sub>2</sub> absorptivity of vegetation covers. However, these researches have mainly focused on plantation forest and temperate forest types.
- CO<sub>2</sub> market has been eventfully taking place on the international one, especially in Europe. However, trade exchange is based on restricted expenditures when CO<sub>2</sub> is eliminated, without scientific basis on calculation for CO<sub>2</sub> absorptivity of natural forest .
- Although Vietnam participated in Kyoto Protocol, these problems have not been paid enough attentions yet, lacked information, scientific basis, calculation methods as well as forecast of CO<sub>2</sub> absorptivity of

national vegetation cover, which is considered as a basis to participate in the global CO<sub>2</sub> market.

## **CHAPTER 2: OBJECTIVES – OBJECTS - CONTENTS – METHODOLOGY**

### **2.1 RESEARCH OBJECTIVES**

#### **Methodologically:**

Research objectives make contributions to apply and develop quantitative measures and forecast CO<sub>2</sub> absorbability capacity for natural forest, which is considered as a basis to define environmental expenditures in forest management.

#### **Practically:**

- i. To define CO<sub>2</sub> sequestration for woody vegetation and its other sections above ground.
- ii. To quantize CO<sub>2</sub> absorbing capacity for forest tree and forest stand.
- iii. To forecast economic value based on CO<sub>2</sub> absorbing capacity of natural forest status.

### **2.2 Research hypothesis**

To make research for this thesis, some important hypotheses are set up:

- There is a considerable change in CO<sub>2</sub> absorbing capacity in different forest types, status, and growth stages.
- It is possible to calculate CO<sub>2</sub> accumulation for forest status as basis to pay for environmental service fees.

### **2.3 Scope, Object and Characteristics of Research Area**

#### **2.3.1 Research Scope and Object**

In the scope of the time limit, human resource and M.sc thesis requirements, the research thesis is restricted as follows:

*Forest type and forest status for research: natural broad-leaved evergreen forests on the three common classes; young forest (IIAB), poor forest (IIIA<sub>1</sub>) and moderate forest (IIIA<sub>2</sub>)*

*CO<sub>2</sub> accumulation for woody vegetation: Research for CO<sub>2</sub> absorbability capacity in its other sections above ground such as: stem, bark, branch and leaf with their diameter of 10cm upwards.*

*Recommendations on prices for CO<sub>2</sub> accumulation of forest status to set up a foundation to develop environmental service payment policy.*

*Research area:* Tuy Duc district, Daknong province.

### **2.3.2 Description of research area**

#### **Tuy Duc district's fundamental information:**

The total natural area: 112 327.00 ha in which: the forested area: 74 572.94 ha; the agricultural land area: 29 448.34 ha; the bare land and treeless hill : 3 601.00 ha; other land area: 4 704.72 ha.

Administrative borders: the north to Cambodia, the east to Daksong district, Daknong province, the west to Binh Phuoc province, the south to DakR'lap district, Daknong province.

#### **Natural conditions of Research Area:**

*Topography:* Research area has its complex topography, separated from thick stream systems with elevation from 650m to 750m;

*Climate and Hydrography:* Here is the climate divided into two reasons. The rainy season is from May to October and the dry one does from November to April in the next year. The average annual temperature reaches at 22.2°C; The average rainfall does at 2 360 mm;

*Land:* Brownish red soil on Bajan (Fk) is rather fertile, with its soil layer depth >100 cm, without lime union, low stone mixture. Silt near streams has a little raised the level of the soil; however, inundation happens in the rainy season.

#### **Forest and forest resources:**

The forests in Tuy Duc is characterized by natural broad-leaved evergreen forests with diversified flora and structure. It is common that young forest restored after cultivation (IIA-IIB), intensively selected harvesting forest (IIIA<sub>1</sub>) and slightly-disturbed forest are all in existence (IIIA<sub>2</sub>). In general, forest whose timber reserve is slightly high is still rich; however, timber quality goes down because many tree species of precious and rare timber were entirely exploited.

#### **Socioeconomic situation:**

Research area whose has a fairly high rate of M'Nong People is located on Dak R'tih and Dak Buk So communes in Dak R'Lap district (currently Tuy Duc district) in Daknong. The local ethnic communities almost of whom have lived on forest have difficulties in their lives.

Besides timber products, non-timber forestry products and cultivation land, natural forest has become a livelihood of the local ethnic communities throughout forest land allocation.

Forest land allocation based on community have brought some benefits such as land use right and timber and non-timber forestry products exploitation

for the communities. The communities, in reality, depends on timber and non-timber forestry product exploitation, which is not going to bring high benefits for them. Therefore, forest land allocation is required to generate other benefits in order that forest warder has become an equal beneficiary in the course of eco-environmental service payment, watershed forest protection, CO<sub>2</sub> absorbibility and indigenous cultural tradition conservation.

## **2.4 Research Content**

To gain research objectives, the thesis includes the following main contents:

- To make research for the relationship between forest survey factors and forest stand structure traits.
- To set up the relationship model between forest plant biomass and tree-stem dimension.
- To make research for CO<sub>2</sub> accumulation rate forest plant, for the relationship between C and CO<sub>2</sub> in biomass; to define C accumulation rate of each section of plant in comparison with the total C amount of the whole plant; to define CO<sub>2</sub> accumulation rate in contrast with fresh biomass of plants based on species, tree stem sections and dimension.
- To make research for the relationship between CO<sub>2</sub> absorbibility and factors of individual plant survey.
- To forecast CO<sub>2</sub> absorbibility amount according to forest stand criteria.
- To quantize CO<sub>2</sub> absorbibility based on forest stand.

## **2.5 Methodology**

### **2.5.1 Viewpoint and Methodology**

Based on the carbon cycle through photosynthesis to generate biomass, respiration and elimination process of vegetation shows that plant life itself is capable of absorbing CO<sub>2</sub> while source of CO<sub>2</sub> is eliminated air not only through respiration of vegetation but also other sources, however, only vegetation is capable of absorbing CO<sub>2</sub>. This is the capacity of vegetation to diminish the greenhouse effect causing gases. Like this, the research on the amount of C stored in plants in order to find out the amount of absorbed CO<sub>2</sub> is the foundation to define the CO<sub>2</sub> absorbing capacity of various forest types and states.

Subsample taken and analyzed to define amount of C sequestered in wooded-trunk vegetation above ground then denoted under the chemistry-mathematics model to forecast and quantify CO<sub>2</sub> absorbibility capability for each forest class.

## **2.5.2 Concrete Methodology**

### ***i) Data collection method for calculating and setting up correlation and structure of forest:***

Typical sample plots based on group for forest status are used for research. 41 sample plots with the area of 900m<sup>2</sup> are classified according to forest status as follows; Young: 14 sample plots, Poor: 12 sample plots and moderate: 15 sample plots. Ecological factor investigation includes: forest status, vegetation cover, vegetation species and canopy cover of forest, ... Timber tree floor investigation consists of: tree species name, diameter at breast height, and quality.

### ***ii) Data collection method for C analysis:***

Sample designing based on method accessible to forest status was set up by Kurniatun Hairiah and the fellows (ICRAF).

The size of sample plot: 20 x 100m is to be investigated for calculating C for the plant with  $D_{1,3} > 30\text{cm}$  and the area of subsample plot: 5 x 40m is to be investigated for calculating C for the plant with  $5\text{cm} < D_{1,3} < 30\text{cm}$ . The samples which are withdrawn from three common forest status of research area are young forest restored after cultivation (IIAB), strongly harvesting forest (IIIA<sub>1</sub>) and lightly disturbed forest (IIIA<sub>2</sub>). The sample plots are typical for each forest status; six sample plots are analyzed according to forest status as follows: Young: 2 plots, poor: 2 plots and moderate: 2 plots.

Division with the diameter of 10cm: <10cm, 10-20, 20-30, 30-40, 40-50 and >50cm. Sample withdrawal rate analytic with each diameter reaches at 10% of the plants in the sample plots, as result of 34 trees.

Four sections of tree: stem, bark, branch, and leaf are weighted and measured by the total mass of fresh biomass (then named biomass, symbolized by SK(biomass)) and the subsample of 1.0kg/section is taken from each section of tree, independently managed according to each tree and clearly coded to avoid being used by chance.

### ***iii) Subsample analysis method in laboratory to find out CO2 content in all parts in stem:***

Analyzed criteria includes: rate of % dry substances, mineral, ash and C.

The total of subsamples used in the laboratory are 136 of 34 trees each of which includes four sections such as: stem, bark, branch and leaf. The analysis

of CO<sub>2</sub> content is in process in the Biological Botany Laboratory, Agricultural and Forestry Department, Tay Nguyen University.

***iv) Imitating the relationships, structural specific characteristics of forest status***

Forecasting CO<sub>2</sub> accumulation based on the factors of individual tree as well as forest stand and setting up the relationships between factors of individual tree investigation and forest stand are required for this research.

- According to the data of 41 sample plots of 900m<sup>2</sup>, distribution of N/D for each forest status based on Mayer content on Excel chart is imitated.

- According to the data of the measure of D<sub>oi</sub> for 10 equal sticks of 34 analytic trees, tree volume is calculated accurately. The relationship model between V(volume) and the two factors of D (diameter) and H (height) based on linear exponential function is built up to check the existence of the correlation coefficient R<sup>2</sup> and the parameters with P<0.05. Using the analysis of the interrelationship on Excel chart and the selection of the optimal function with the highest R<sup>2</sup> is to set up the interrelationship H/D.

***v) Research method for the relationship between biomass and tree-stem dimension.***

Fresh and dry biomass of tree and each section is calculated based on the data analysis of 34 analytic trees. The relationship between fresh biomass and dry one, biomass and tree diameter on Excel is built up to select the appropriate function.

***vi) Method to identify CO<sub>2</sub> rate accumulated in trees:***

From C amount identified through the analysis, CO<sub>2</sub> amount which vegetation absorbs and O<sub>2</sub> is harmonized in the atmosphere is calculated through the chemistry equation: CO<sub>2</sub> = C + O<sub>2</sub>; CO<sub>2</sub> = 3.67C

The relationship analysis:

- The relationship between CO<sub>2</sub> with the fresh biomass on Excel and the selected optimal function.

- The analysis for one-factor variance consists of type, stem-tree parts, diameter to evaluate the difference of %C from the fresh biomass of these factors.

***vii) Method to estimate CO<sub>2</sub> absorbed in forest trees and forecast for forest stand.***

The model method of mathematics imitating CO<sub>2</sub> absorptivity capability in forest trees and forest stand for forest survey factors of individual trees and forest stand is applied for:

- The dependent variable of  $y$  is CO<sub>2</sub> amount of forest trees or CO<sub>2</sub>/ha of forest stand.

- The independent variable is  $x_i$  including forest variables (D (diameter), H (height), V (volume), G (basal are), M (yield), N (density))

- The appropriate relationship is surveyed and selected by nonlinear functions and linear ones; the correlation coefficients like  $R$  or the relative ones like  $R^2$  are checked by the criteria based on  $F$  at the error of  $P < 0.05$  and the existence of each independent variable on the criteria  $t$  at the error  $P < 0.05$ .

### CHAPTER 3: RESULTS AND DISCUSSION

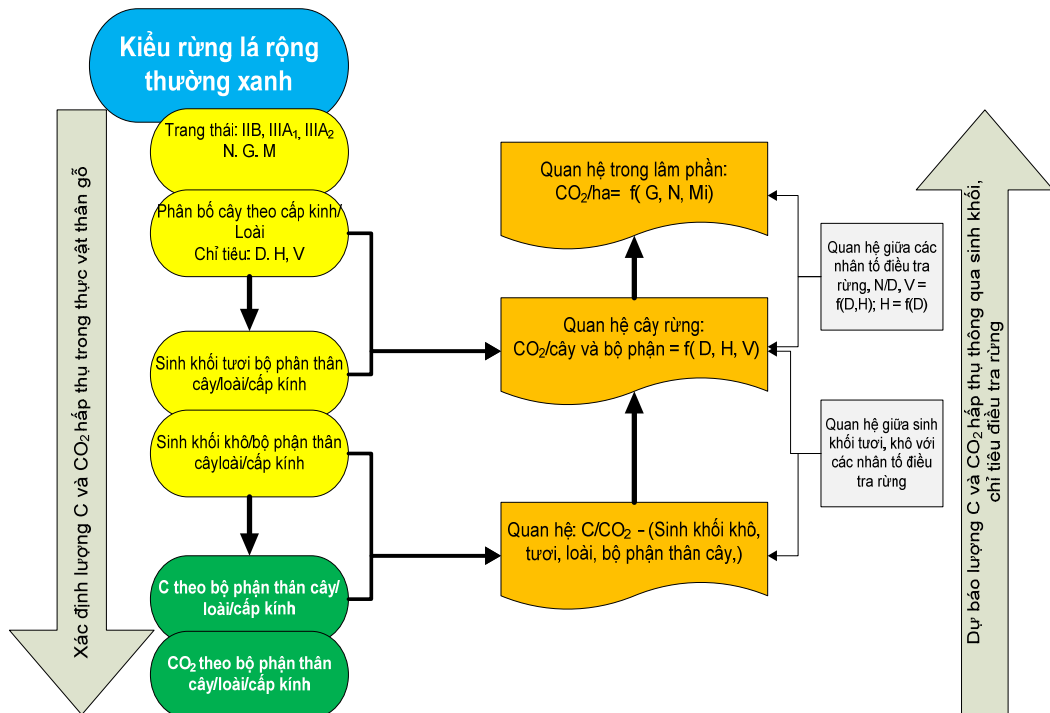


Figure 3.1: The diagram to analyse C amount in wooded-stem vegetation and to forecast CO<sub>2</sub> amount accumulated individual tree and forest stand

#### 3.1 The relationship between factors of forest survey and structural characteristics as well as distribution of forest stands.

The interrelative models between the criteria of individual tree and forest stand survey must be set up to forecast C and CO<sub>2</sub> amount and the structural rules and distribution of forest status should be modeled.

### 3.1.1 The correlation of individual tree survey

From the data of  $D_{1.3}$ , Hcc (height from base to apex) for 34 analytic trees, the statistical math function on Excel software resulting in the imitative interrelation of diameter and height is represented by the following equation 3.1

$$H = 3.271.D^{0.526} \quad (3.1)$$

within  $N = 34$ ;  $R = 0.936$ ,  $F = 227.282$ ,  $\alpha < 0.000$

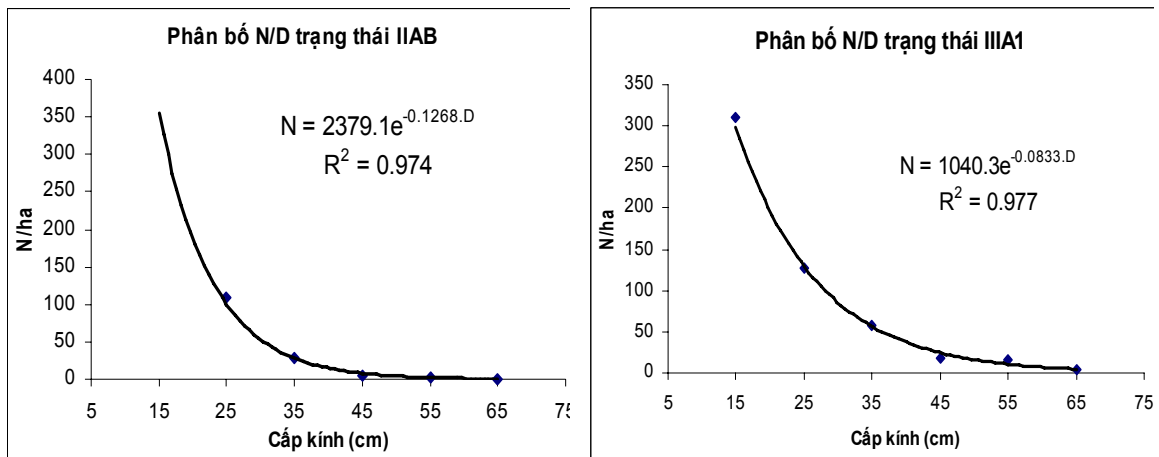
The result of the relationship model between the tree volume based on the diameter and its height:

$$V = 3.04323E-05.D^{1.374}.H^{1.921} \quad (3.2)$$

within  $N = 34$ ;  $R = 0.980$ ;  $F = 383.3504$  at error  $\alpha < 0.000$

### 3.1.2 The density distribution and yield based on the diameter

The diameter and density distribution (N/D) is built up by the data of field survey for 41 sample plots represented for different forest status. Using Mayer exponential function to describe the structure of  $N/D_{1.3}$  based on forest status shows the results  $R^2 > 0.9$  with  $P < 0,05$  from the following figures:



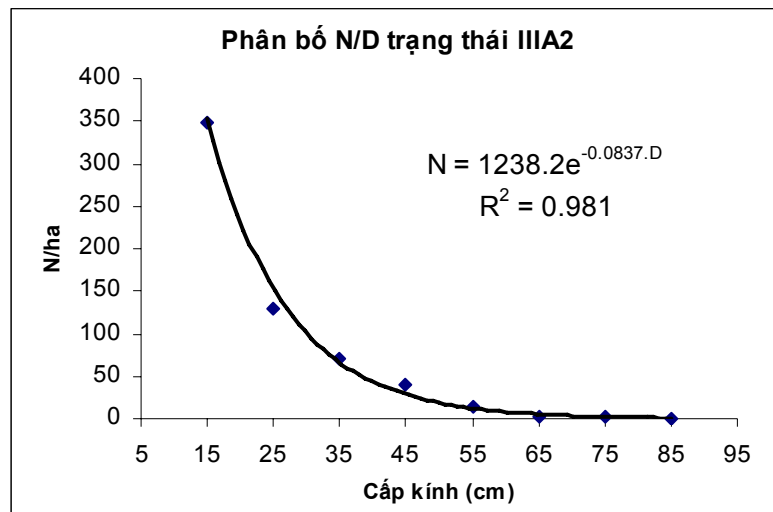
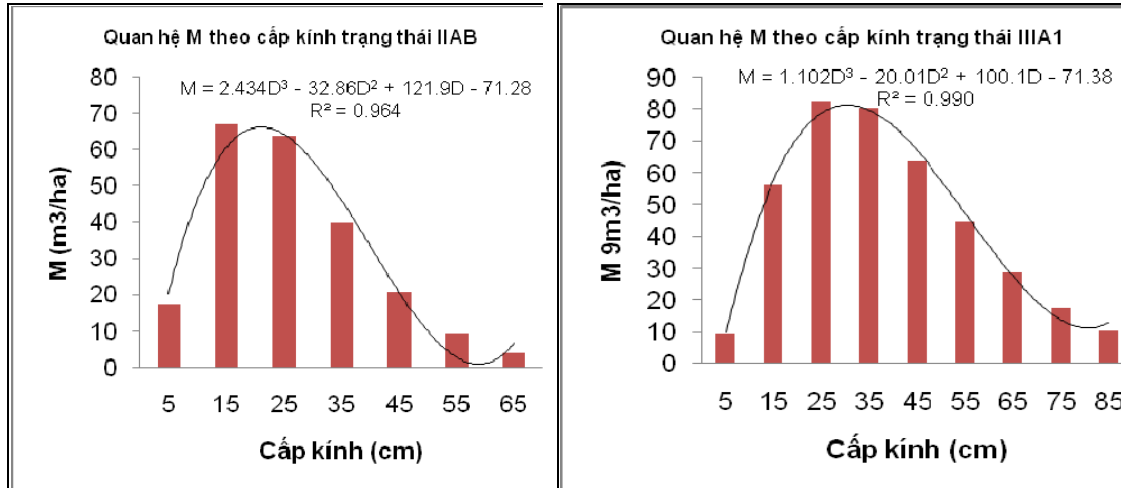


Figure 3.3: N/D analysis description for the three forest status based on Mayer exponential

Based on the descriptive model for the relationship between  $N-D_{1.3}$ ,  $H-D_{1.3}$  and  $V=f(D_{1.3}, H)$  built as the above, the theoretic data diagram for the density ( $N/ha$ ), the height ( $H$ ), the volume ( $V$ ) and the yield ( $M$ ) ( $m^3/ha$ ) based on the diameter of each forest status needs building up.



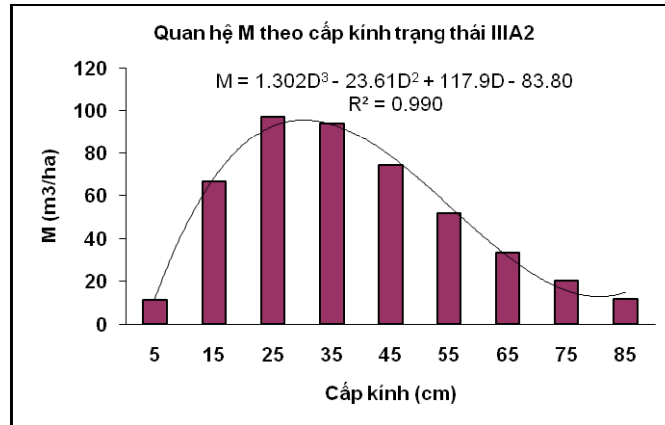


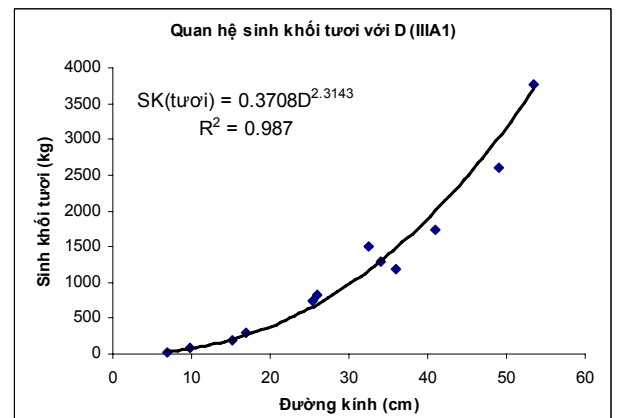
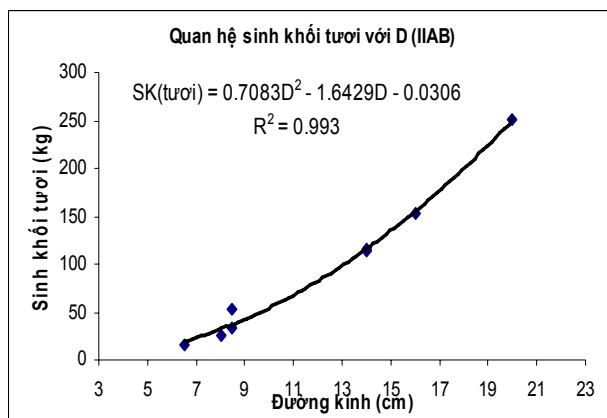
Figure 3.4: The yield distribution based on the diameter of the three forest status

Through the interrelative models, the relationship of the forest survey criteria between individual trees and forest stands,  $N/D$  and  $M/D$  in the three forest status are considered as an intermediary basis to forecast  $CO_2$  amount absorbed in timber trees and forest status. Furthermore, the relationship between  $C$  or  $CO_2$  amount and one of the forest survey criteria is possible to be inferred  $C$  and  $CO_2$  for each forest tree or each forest stand.

### 3.2 The relationship model of forest tree biomass based on the diameter of each forest status

The  $C$  content accumulated in forest tree can be identified through the chemicals analyzed in the dry biomass. Therefore, the basis considered as to identify  $C$  amount in the vegetation direct to fresh or dry biomass or indirect to the forest survey criteria is research on the relationship between the fresh biomass of all sections of tree stem with the individual tree survey resulting in  $D_{1.3}$  and  $H$  and the fresh biomass compared with the dry one.

The result of finding out the imitative relationship the fresh biomass and the two factors of  $D_{1.3}$ ,  $H_{cc}$  on the diagram in Excel software is represented by the graphs in the following figures.



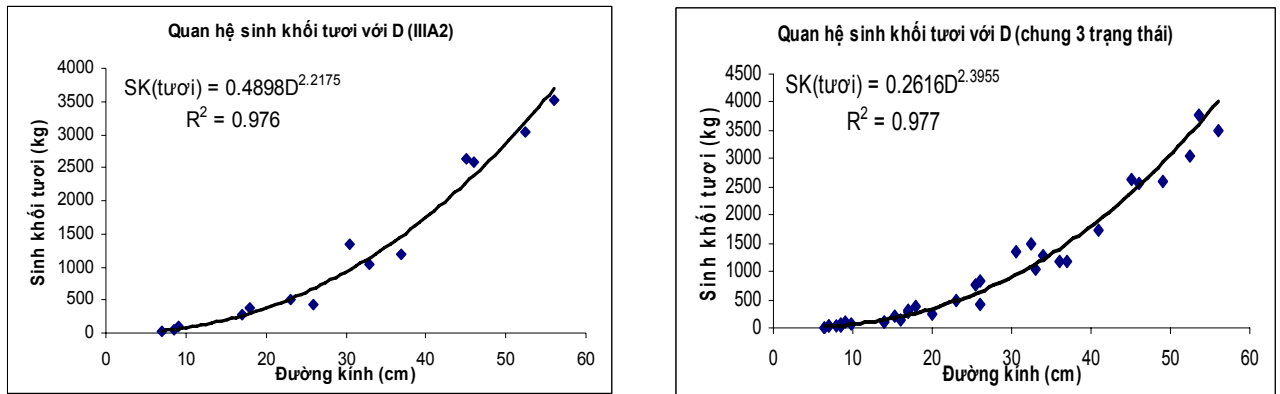


Figure 3.5: The relationship of the fresh biomass based on the diameter of forest status.

In general, there has not been any big difference among the changes of the biomass based on the diameter of forest status, the equation is possible to be used for each forest status if requested to be quickly examined, the general relation equation can be applied.

With this relationship, in reality, there is no need to cut down the tree stem but the fact that the fresh biomass of the total tree stem including stem, bark, branch and leaf can be forecasted is the accurate method based on the measuring and accounting criterion simply considered as  $D_{1.3}$  (cm).

In addition, when C amount in each part of tree stem is identified from its dry biomass, it is necessary to set up the relationship between the fresh biomass and the dry one to forecast the C amount based on the fresh or dry biomass.

The relationship result of dry biomass (SK(Kho)) and the fresh one (SK(Tuoi)) of the tree stem is an exponential function:

$$SK(Kho) = 0.454.SK(Tuoi)^{1.032} \quad (3.3)$$

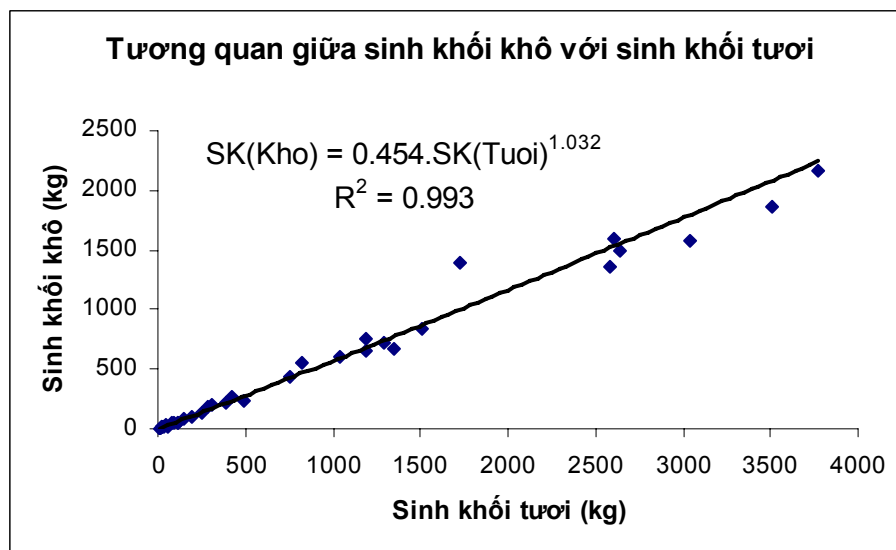


Figure 3.6: The interrelation between the fresh biomass and the dry one of the forest tree stem

### 3.3 C rate accumulated in forest tree

#### 3.3.1 The relationship of the amount of C and CO<sub>2</sub> accumulated in the forest tree stem compared with the biomass

From the 34 dried fresh subsample analytic trees, their C amount is analyzed to find out C amount from each part of the tree stem and itself. CO<sub>2</sub> amount which the tree absorbs is calculated based on the following formula: CO<sub>2</sub> = 3.67C.

The relationship establishment between C accumulated amount and the biomass of the total tree shows the best imitative exponential function with R<sup>2</sup> = 0.999 and P<0.05

$$C(\text{kg}) = 0.401 \text{ SK}(\text{kho})^{1.003} \quad (3.4)$$

From this result, the C amount accumulated in the tree can be quickly calculated while C amount through the fresh biomass can be based on the fresh and dry biomass relationship.

$$C(\text{kg}) = 40.1\% \text{ SK}(\text{Kho}) = 18.2\% \text{ SK}(\text{Tuoi})(\text{kg})$$

Which also allows the average absorbed CO<sub>2</sub> amount of the individual tree to be forecasted as follows:

$$\text{CO}_2 (\text{kg}) = 3.67C = 66.8\% \text{ SK}(\text{Tuoi})(\text{kg}). \quad (3.5)$$

From the fresh biomass of the forest tree, the CO<sub>2</sub> amount which the forest tree absorbs can be quickly calculated while the relationship between the fresh biomass and the diameter D can be used to find out the fresh biomass without cutting down the tree to weight and measure the biomass of the tree.

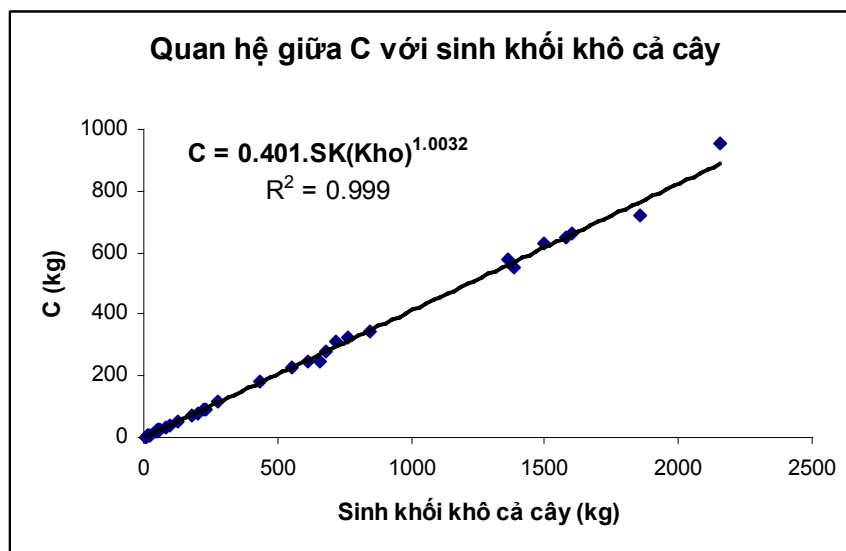


Figure 3.7: The relationship between the C amount accumulated with the dry biomass of the forest tree

### 3.3.2 The C rate accumulated in each part of the tree based on the diameter.

The components of C is individually analyzed according to each part of the tree above ground and arranged by their diameter intervals which results in calculating the rate of % of the C amount accumulated in each part of the tree compared with the total amount of C accumulated in the tree, which is called (%C<sub>1</sub>).

The result shows that the tree stem is the one containing the highest rate of C of 62% and the leaf containing the lowest rate of C of 2%, which is compared with the one of the total tree.

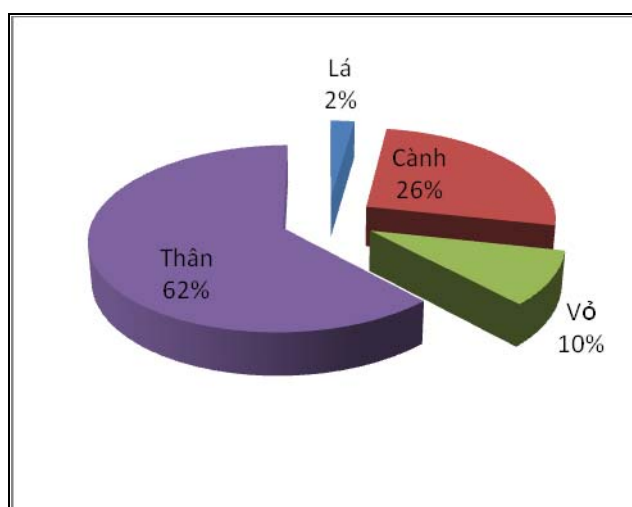


Figure 3.9: The rate of % at the average C amount in each part of the tree compared with the total amount of C accumulated in the tree.

### 3.3.3 The rate of C accumulated in comparison with the tree's fresh biomass among tree types, parts of tree, and their diameter.

To assess the change of the C amount accumulated in the tree based on the factors related to the species and the growth, using the criterion of % of the C amount accumulated in comparison with the fresh biomass of the tree (%C<sub>2</sub>) allows checking the difference or no difference reaching at % C among the species factors, other parts of the tree, and their diameter intervals.

% C difference is checked as the following factors:

- Among the species
- Among the parts of the tree
- Among the diameter intervals

The analyzed result of the variance shows the difference exists among the species and the parts of the tree, which there is the difference of % C from the

fresh biomass. This means that CO<sub>2</sub> absorptivity capacity among the types and the parts of the tree such as stem, bark, branch and leaf is unsimilar. Therefore, when absorbed CO<sub>2</sub> is accurately calculated, each part of the stem and the species need identifying. However, it is, in reality, complicated to identify each part of the stem because the forest tree needs cutting down to classify its parts, weight the amount of the biomass, analyze the content of C in each part,...so the research set up the relationship to be forecasted between CO<sub>2</sub> and the other factors. Besides the accumulated C amount depends on the ecological characteristics of the types. The accumulated C content is recognized by the species; however, the practical application of the procedure meets difficulty in mixed uneven - aged natural forest because there must be hundreds of species on 1 ha in this kind of forest. Therefore, in the initial step, the average C amount accumulated in the species needs to be accepted.

### 3.4 The relationship between the absorbed CO<sub>2</sub> and the factors of the individual tree survey.

According to the results of the above researches, the absorbed C amount depends on the species and can be changed by its part of the stem, dimension and biomass so that the relationship between CO<sub>2</sub> absorbed in the total tree for each species and the factors for the diameter, height, and volume of the standing tree.

From the data resulted from the analysis of 34 analytic trees, the relationship of the single table and the multi ones in Statgraphics Plus Software and SPSS is in process to find out the relationship between the CO<sub>2</sub> absorbed in the total tree and the factors such as D<sub>1.3</sub>, H, V, and the species. The selection of relative optimal function through the highest relative coefficient existing with the level of P<0.05 accompanied with multi variable function is applied to check the existence of the coefficients based on the criteria similar to P<0.05; at the same time that the suitability of the relationship is considered to be assessed by the natural rule. As a result, the firm relationship between CO<sub>2</sub> and the three individual tree survey factors is found out by D, H and V.

*Table 3.10: The result found by the relationship between the CO<sub>2</sub> absorbed in the tree in comparison with the individual tree variables*

The relative functions	Relative functions R <sup>2</sup>	P with R <sup>2</sup>	
$\ln(\text{CO}_2) = -1.78618 + 2.4799 \cdot \ln(D)$	0.984	< 0.05	(3.6)
$\ln(\text{CO}_2) = -5.97036 + 4.20777 \cdot \ln(H)$	0.938	< 0.05	(3.7)
$\ln(\text{CO}_2) = 6.64564 + 1.02182 \cdot \ln(V)$	0.979	< 0.05	(3.8)
$\text{CO}_2 = -337.456 + 410.225V + 29.558D$	0.927	< 0.05	(3.9)

$$\ln(\text{CO}_2) = -1.78618 + 2.4799 \cdot \ln(D) \quad (3.10)$$

This function is used to estimate the  $\text{CO}_2$  amount absorbed in the standing tree according to the simply-investigated criterion of the height breast diameter of ( $D_{1.3}$ ).

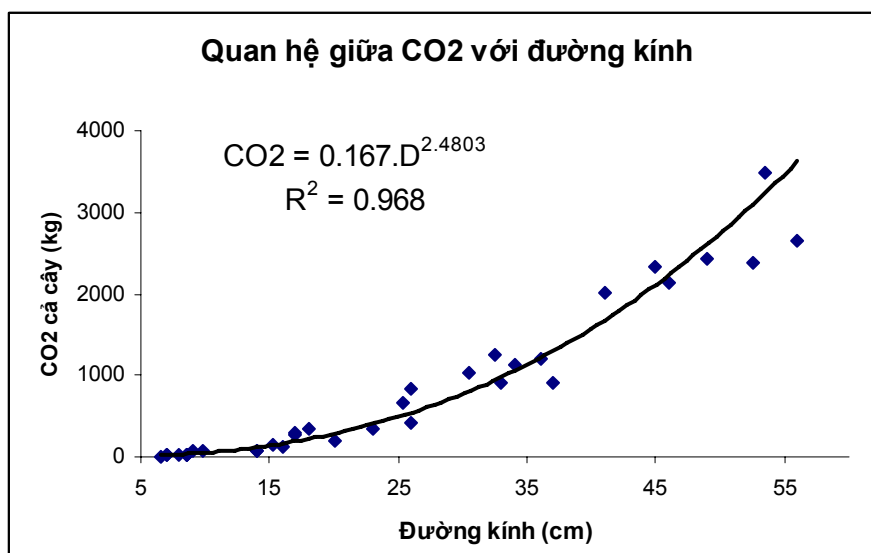


Figure 3.12: the relationship model between  $\text{CO}_2$  and  $D$

At the same time that the relationship between the  $\text{CO}_2$  amount absorbed in each part of the stem and the individual tree survey criteria is built up.

Table 3.12: The result found out by the relationship between the  $\text{CO}_2$  amount of the four parts of the stem and the individual tree variables

The relative functions found out	The relative functions with $R^2$	P with $R^2$	
$\ln(\text{CO}_2 \text{ stem}) = 6.15398 + 1.02468 \cdot \ln(V)$	0.971	< 0.05	(3.11)
$\ln(\text{CO}_2 \text{ bark}) = 4.11447 + 1.06381 \cdot \ln(V)$	0.936	< 0.05	(3.12)
$\ln(\text{CO}_2 \text{ branch}) = -4.11248 + 2.70337 \cdot \ln(D)$	0.830	< 0.05	(3.13)
$\ln(\text{CO}_2 \text{ leaf}) = -2.941 + 1.72414 \cdot \ln(D)$	0.861	< 0.05	(3.14)

The relative error of the two measuring methods for  $\text{CO}_2$  has been checked:

- The estimation for  $\text{CO}_2$  of the total tree through the diameter is described by the table of 3.10 in which the great fluctuation error averages at 4.43% so that this method can be applied for the quick survey or calculation for many trees to infer for the forest stand.

- The estimation for CO<sub>2</sub> of the total tree through the one for CO<sub>2</sub> of the four parts of the tree such as stem, bark, branch and leaf carried out by the four functions from 3.11 to 3.14 shows that the relative error is very low, averaging at 1.38%. This method is used when CO<sub>2</sub> needs estimating accurately for each individual tree.

### 3.5 Forecast for CO<sub>2</sub> based on the criteria of the forest stand

In practice, CO<sub>2</sub> absorbed in each area unit or each forest stand is necessary to be quantified, which is considered as a basis to assess the economic value of the environmental service. To carry out this process, CO<sub>2</sub> can be withdrawn from the sample and calculated for each tree, which is based on the estimative equation for the individual tree or for each part of the stem according to the above result to infer from the forest stand, which creates the high result with the highest accuracy; however, in many cases, CO<sub>2</sub> absorbed in the forest stand needs to be quickly appraised to calculate the environmental value as well as to supervise CO<sub>2</sub> accumulation on time and on the large scale, which demands the approach with the faster parameter and gain the confidence as expected.

The research has been looking for the relationship between the total absorbed CO<sub>2</sub> amount per ha and the factors of the forest stand survey such as the average diameter ( $D_{bq}$ ), the average height ( $H_{bq}$ ), the density (N/ha), the total basal area (G/ha) and the forest status (mainly 3 types young, poor and moderate). The data from the sample plots are used to calculate the following variables:

*The dependent variable CO<sub>2</sub>/ha in the forest stand:* Based on the four equations to identify CO<sub>2</sub> amount for each part of the stem to calculate each part such as stem, bark, branch, and leaf, which can be calculated for the total tree and inferred for ha.

*The independent variable:*

$D_{bq}$ ,  $H_{bq}$ : The average calculation of the tree based on its diameter intervals.

N/ha: The total of the trees with the diameter intervals in each sample plot

G/ha: Based on N/D of the sample plots, G of the sample plot can be calculated and inferred

The status is coded IIAB = 1, IIIA<sub>1</sub> = 2 and IIIA<sub>2</sub> = 3

SPSS software is used to test and select the variable which has the relationship to CO<sub>2</sub>/ha through the variable stepwise regression method to find

out the variable which has the firm relationship to the dependent one at the error of  $P < 0.05$

The result of the application for this method with the following equation:

$$\text{CO}_2/\text{ha (kg)} = - 53242.2 + 11508.035 G (\text{m}^2/\text{ha}) \quad (3.15)$$

with  $R^2 = 0.987$ ,  $P < 0.05$

The above result shows that  $\text{CO}_2$  only related to one factor of the forest stand is  $G/\text{ha}$  and the other ones are excluded from the model such as  $D_{\text{bq}}$ ,  $H_{\text{bq}}$  and  $N/\text{ha}$  while the relationship of the  $\text{CO}_2$  absorbed in each status has not been discovered yet.

In reality, this result is an advantage to identify the  $\text{CO}_2$  amount absorbed in each other forest stand timely, which is considered as a basis to calculate the environmental service fee on the large scale.

The result of the model shows that the absorbed  $\text{CO}_2/\text{ha}$  amount changes according to the biomass on ground represented through  $G/\text{ha}$ .

From the results, the  $C$  or  $\text{CO}_2$  amount absorbed in the woody vegetation in the forest status can be summarized by the application based on the following diagram:

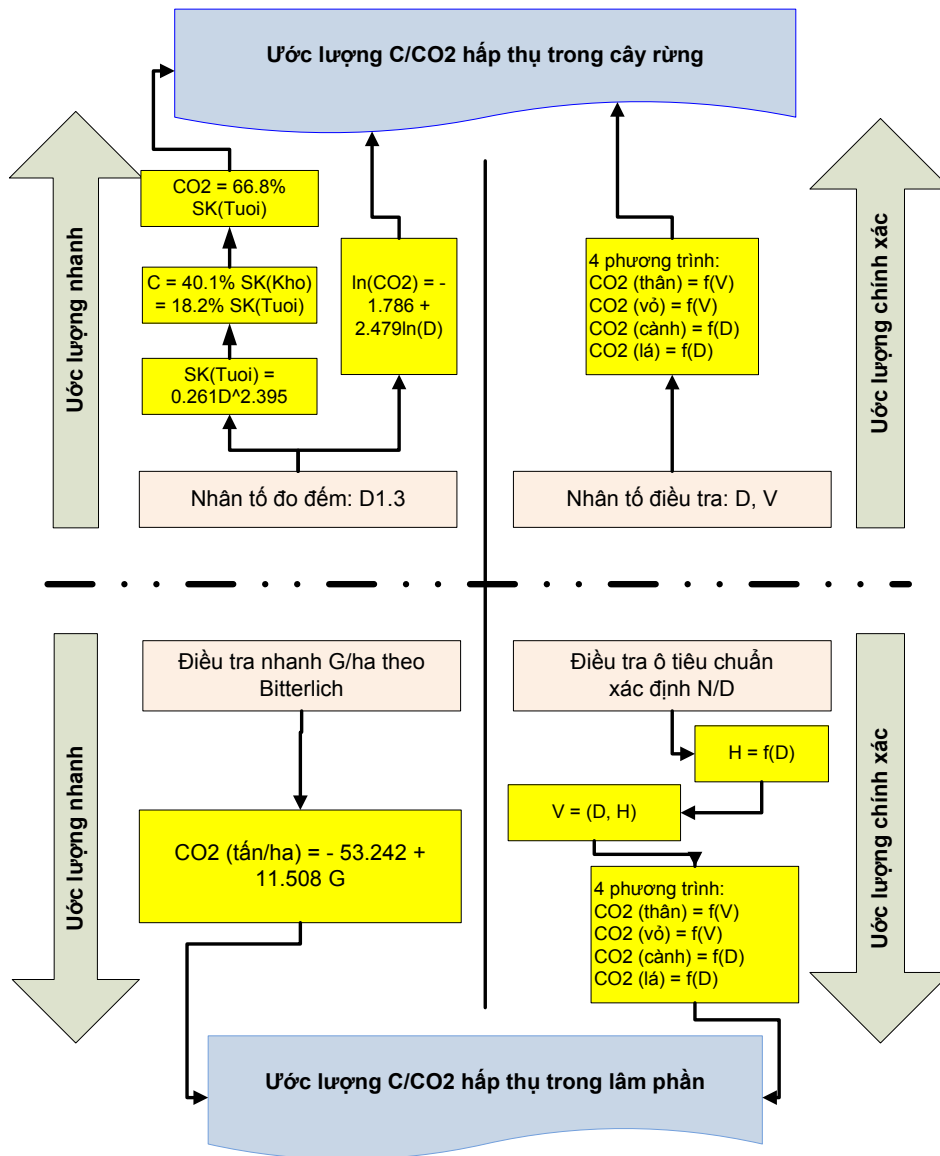


Figure 3.14: The diagram to forecast CO<sub>2</sub> absorbed in forest tree and forest stand

### 3.6 The quantification for CO<sub>2</sub> absorbed in the forest stand

The purposes of the quantification and assessment for CO<sub>2</sub> absorptivity capacity of the forest tree aims at:

i) Assessing accumulated CO<sub>2</sub> capacity in the forest tree to appraise the released-gas absorbed capacity which brings about the effect for the greenhouse. Based on the research results of the thesis, from the data of the existing forest resource as well as the forest survey criteria through G/ha of each forest status, the managers can forecast CO<sub>2</sub> amount accumulated in natural forest, creating the firm foundation to provide the strategic planner for the natural forest with the environmental function

ii) Quantifying the absorbed CO<sub>2</sub> capacity of the other forest status and forest stands, which is expected to create a scientific basis as well as tools and methods to assess the CO<sub>2</sub> accumulated in the forest tree and forest status types

in order to forecast CO<sub>2</sub> accumulated timely.... The thesis has made a partly contribution as described in the above results, which is considered as a basis to develop the policy as well as to participate in the programmes, projects (CDM), CO<sub>2</sub> market in the nation and the world.

Based on CO<sub>2</sub> market evaluation with the lowest price of 11USD/ton of CO<sub>2</sub> in combination with the estimation of CO<sub>2</sub> capacity absorbed in the natural forest status which allows forecasting the economic effect on the environmental service supply and on sale.

*Table 3.16: The prediction for the economic effect on CO<sub>2</sub> amount absorbed in the natural forest status*

Status	Basal area G (m <sup>2</sup> /ha) at time A	G (m <sup>2</sup> /ha) at A+1 corresponding to grow per year 1.5%G/year	Yearly absorbed CO <sub>2</sub> (ton/ha)	Price (USD/ton CO <sub>2</sub> )	Yearly Accumulative value CO <sub>2</sub> year/ha (USD)	Yearly Accumulative value CO <sub>2</sub> year/ha (VND)
IIAB	10	10.15	1.73	11	19	303,811
IIIA <sub>1</sub>	20	20.3	3.45	11	38	607,622
IIIA <sub>2</sub>	30	30.45	5.18	11	57	911,434

CO<sub>2</sub> amount absorbed in forest status every year can be calculated through the model forecasting CO<sub>2</sub> through G/ha:

$$\text{CO}_2 \text{ (ton/ha)} = - 53.242 + 11.508 \text{ G (m}^2\text{/ha)}$$

In G/ha in turn in the two at the two same times A and A+1 into the equation and the difference can be calculated.

The yearly value of accumulated CO<sub>2</sub> per ha is calculated through CO<sub>2</sub> yearly amount absorbed multiply with 11USD/ton CO<sub>2</sub>, which exchanges into VND.

The forecasting results show that if the forest protection is in good process, the yearly absorbed amount of CO<sub>2</sub> reaches from 1.73 to 5.18 ton per ha per year, which is equivalent to the market price of CO<sub>2</sub> from 300.000 to 900.000 VND per ha per year. This money is valuable enough for forest managers, specially for ethnic communities in the highland.

## CONCLUSION AND RECOMMENDATION

### Conclusion

From the research results, the thesis makes the following main conclusions':

#### 1) The relationship between the factors of the forest survey and the structural characteristics, the distribution of forest status.

*The interrelation among the criteria of the individual tree survey*

$$H = 3.271.D^{0.526} \text{ and } V = 3.04323E-05.D^{1.374}.H^{1.921}$$

*The density distribution and volume based on the diameter*

$$\text{Status IIAB: } N = 2379.e^{-0.12D}$$

$$\text{Status IIIA}_1: N = 1040.e^{-0.08D}$$

$$\text{Status IIIA}_2: N = 1238.e^{-0.08D}$$

*The volume relationship based on the diameter*

$$\text{Status IIAB: } M = 2.434D^3 - 32.86D^2 + 121.9D - 71.28$$

$$\text{Status IIIA}_1: M = 1.102D^3 - 20.01D^2 + 100.1D - 71.38$$

$$\text{Status IIIA}_2: M = 1.302D^3 - 23.61D^2 + 117.9D - 83.80$$

In reality, this model is applied to identify quickly the reserves (m<sup>3</sup>/ha) of the status such as evergreen forest in the research area through the diameter (D<sub>1.3</sub>).

#### 2) The biomass relationship model on the diameter of each forest status

The relationship between the dry biomass and the fresh one is described by the linear function with the high relative coefficient

$$SK(\text{Kho}) = 0.454.SK(\text{Tuoi})^{1.032}$$

With this coefficient, in reality D<sub>1.3</sub> is measured to forecast the fresh biomass of the total stem.

#### 3) The C rate accumulated in the tree

*The relationship between C and CO<sub>2</sub> accumulated in the stem with the biomass is*

$$C(\text{kg}) = 0.401 SK(\text{kho})^{1.003}$$

$$C(\text{kg}) = 40.1\% SK(\text{Kho}) = 18.2\%SK(\text{Tuoi})(\text{kg})$$

$$CO_2(\text{kg}) = 66.8\% SK(\text{Tuoi})(\text{kg})$$

*The sequestrated C in comparison with the fresh biomass of the forest tree among the trees in the types, each section of the stem and the diameter intervals:*

The result of variance analysis shows that there is the difference concerning about % C from the fresh biomass among the forest types and parts of the stem. This means that C amount which is accumulated depends on the physiological characteristics of the tree species and the parts of the wooded stem. Therefore, The identification of the accumulated C is necessary to be in process according to the type. Furthermore, to be applied in practice is to have difficulties in multitude of plant species of natural forest because the number of tree species on the area unit is very complicated. In the initial step, the accumulated C average amount is necessary to be accepted for all the types.

#### **4) The relationship between absorbed CO<sub>2</sub> amount and the individual tree survey factors**

*The relationship between CO<sub>2</sub> of the total tree and the individual tree survey factors:*

$$\ln(\text{CO}_2) = -1.78618 + 2.4799 \cdot \ln(D)$$

*The relationship between CO<sub>2</sub> of the four sections of the tree and the individual tree survey:*

$$\ln(\text{CO}_2 \text{ stem}) = 6.15398 + 1.02468 \cdot \ln(V)$$

$$\ln(\text{CO}_2 \text{ bark}) = 4.11447 + 1.06381 \cdot \ln(V)$$

$$\ln(\text{CO}_2 \text{ branch}) = -4.11248 + 2.70337 \cdot \ln(D)$$

$$\ln(\text{CO}_2 \text{ leaf}) = -2.941 + 1.72414 \cdot \ln(D)$$

In reality, CO<sub>2</sub> of the total tree is applied to estimate quickly CO<sub>2</sub> for each forest tree, if the correctness rate is requested to be high, the specific formula should be applied for each part.

#### **5) The forecast of CO<sub>2</sub> amount based on the forest stand criteria**

The processing result of the stepwise regression method shows that CO<sub>2</sub>/ha amount firmly related to the total width section on (G/ha) through the following equation:

$$\text{CO}_2/\text{ha (ton)} = -53.242 + 11.508G \text{ (m}^2/\text{ha)}$$

This research result applied to investigate quickly CO<sub>2</sub> /ha for forest stand is simple and useful because the value of G/ha is identified (used by Bitterlich ruler).

Besides, the research results can be applied to appraise CO<sub>2</sub> amount absorbed in other forest stand timely, which is considered as a basis to calculate the environmental service fee on the large scale.

#### **6) Qualifying CO<sub>2</sub> absorbed in forest stand**

The research result shows that the yearly accumulated CO<sub>2</sub> is forecasted to gain from 1.73 to 5.18 ton per ha per year for evergreen forest status. The value exchanged into the money from absorbed CO<sub>2</sub> capacity achieves from 300.000VND to 900.000 VND per ha per year, which is dependent on the forest status and forest resource base through G.

In combination with the value taken from the timber and non-timber products as well as the potential environmental service fee payment - CO<sub>2</sub> absorbibility capacity – It is the beneficial source of income which is very meaningful for the forest managers, especially for the ethnic people whose life depends on and identify themselves with the forest.

### **Recommendation**

1. The environmental service fee payment mechanism is essential to be built up through CO<sub>2</sub> absorbibility capacity of the natural forest for the forest owner.

2. For evergreen natural broad-leaved forest, the research results of the thesis need applying to serve for the CO<sub>2</sub> absorbibility capacity appraisal of the forest status in order to build up the environmental service fee policy.

3. Initially, the research results should be applied to experiment the environmental service fee payment mechanism for the forest areas which have been being managed the communities in Daknong province.

4. To create the scientific foundation for the large-scale application of the research results to identify CO<sub>2</sub> absorbibility capacity through the factors of the forest stand, the ongoing researches should be encouraged for the other forest status and types of forest existing in the highlands of Vietnam.