

Forecasting CO₂ sequestration on natural broad-leaved evergreen forests in Daknong province, Vietnam

The increase of carbon dioxide (CO₂) in the atmosphere is becoming a global concern. The amount of CO₂ sequestration depends on forest type, forest status, dominant tree species and forest stand age.



Fig. 1. Landscape of research area

Researches on CO₂ sequestration of each specific vegetation type are thus needed to quantify the economic values of forest, and build payment mechanisms for environmental services.

This is the focus of the Master of Science thesis titled 'Forecasting CO₂ sequestration on natural broad-leaved evergreen forests in Tuy Duc district, Dak Nong province, Vietnam.' The thesis was supported by the Research Fellowship Grant of the Southeast Asian Network for Agroforestry Education (SEANAFE) through the Vietnam Network for Agroforestry Education (VNAFE).

Research site

Tuy Duc district has an elevation of 650-750 m. Rainy season is from May to October, while the dry season is from November to April of the following year. Average rainfall is at 2 360 mm, while the average annual temperature is at 22.2°C.

Bazal soil is prevalent in the area. It is brownish red in color, fertile, and contains less lime and stone mixture. The research site had a soil layer depth of >100 cm at the time of the study.

The forests in Tuy Duc are characterized as natural broad-leaved evergreen forests with diversified flora and structure. The main species are *Schima superba*, *Quercus* sp, *Syzygium* sp, *Cinnamomum* inners, *Melia azedarach*, *Eugenia* sp...

In general, the timber in these forests is still rich. However, timber quality is decreasing because of exploitation.

The district of Tuy Duc is home to the indigenous community of M'Nong. They have lived in the forests and relied on it for timber and nontimber products, land cultivation, and other livelihood activities.

Objectives and hypotheses

The research aimed to contribute in the development and application of quantitative measures and forecasting of CO₂ sequestration for natural forests. Results would serve as basis in defining environmental expenditures in forest management.

Specifically, the research:

- defined CO₂ sequestration for woody vegetation and its other sections above ground;
- quantified the CO₂ absorbing capacity of individual forest trees and the forest stand; and
- forecasted the economic values based on the CO₂ sequestration ability of the natural evergreen forests that were of different status.

From these objectives, the research hypothesized that: 1) there was a considerable change in the CO₂ absorbing capacity of forests considering their types, status, and growth stages; and 2) it was possible to calculate the CO₂ accumulation of forests at different status as basis in paying for environmental service fees.

Scope and limitations

The research was limited in terms of:

- forest type and status as it only considered the natural broad-leaved evergreen forests which were classified as young, poor, and medium;
- CO₂ absorbing capacity of woody vegetation such as the stems, bark, branches, and leaves of the trees with diameter of 5 cm and more; and
- the study site which only considered the natural forest area of 74 573 ha in the Tuy Duc district, Dak Nong province Vietnam.

Methods and analyses

Based on the carbon cycle and the photosynthesis process in generating biomass, the respiration and elimination of vegetation showed that plants were capable of absorbing CO₂. This ability helps reduce the effects of greenhouse gases.

This was used as the basis of the research. The amount of carbon stored in the plants was determined to find out the amount of CO₂ that had been absorbed. The results were then used to determine the CO₂ absorbing capacity of the forest trees and the forest stand.

Subsamples were taken and analyzed to define the amount of carbon sequestered in the different wooden parts of the forest trees. A mathematics model was then used to forecast and quantify the CO₂ absorptive capacity of each forest status.

With these considerations, the research was implemented through the following specific methods and analyses:

Collecting data for carbon sequestration analysis. Sample plots, measuring 20 m x 100 m, were established to calculate the carbon accumulated in plants with DBH > 30 cm. Subsample plots, measuring 5 m x 40 m, were also established to calculate the carbon accumulated in plants with 5 cm < DBH < 30 cm.

The sample sites were established in three common forest statuses – young forest restored after cultivation (young), highly harvested forest (poor), and lightly disturbed forest (medium).

Analysis of the sample plots, meanwhile, was broken down as follows: two plots for young forests, two plots for poor forests, and two plots for the medium forests.

The trees' stem, bark, branches, and leaves were weighed and measured in terms of total fresh biomass. A subsample of 1 kg per part was taken from each part of the tree.

Analyzing subsamples for CO₂ content. There were 34 trees that were analyzed from which 136 subsamples were obtained. The different tree parts (stem, bark, branches, and leaves) were then analyzed at the Biological Botany Laboratory, Agricultural and Forestry Department, Tay Nguyen University. Criteria for analysis included the rate of percent of dry substances, mineral, ash, and carbon.

Analyzing biomass and tree-stem dimension relationship. The fresh and dry biomass of each tree part was calculated based on the results of data analysis. The relationship between fresh and the dry biomass, and tree diameter was then built up to select the appropriate function.

Analyzing rate of CO₂ accumulation in trees. The rate of CO₂ accumulation in trees was analyzed based on the relationship between CO₂ and fresh biomass, and the selected optimal function.



Fig. 2. Analysis of carbon amount in part of trees

One-factor variance was used to evaluate the differences in the accumulated carbon (%) based on the fresh biomass of the trees, tree parts, and tree diameter.

Estimating CO₂ absorption in forest trees, and forecasting for forest stand. A mathematical model was used to analyze the CO₂ absorptive capacity of forest trees and the forest stand. The model was used based on the following assumptions:

- The dependent variable y signified the amount of CO₂ in forest trees or the CO₂ per hectare of forest stand;
- The independent variable x_i included the forest variables DBH (diameter at breast height, cm), H (height, m), V (volume of tree stem, m³/stem), BA (basal area, m²/ha), M (stand volume per ha, m³/ha), and N (density per ha, stem/ha); and
- The appropriate relationship was surveyed and selected using linear and nonlinear functions - the correlation coefficients (R^2) were checked by the criteria based on F with $P < 0.05$ error, and the existence of each independent variable was based on the criteria t with $P < 0.05$ error.

Results

Rate of carbon accumulated in each tree part.

The components of carbon were individually analyzed according to each tree part. The percent rate of carbon that was accumulated in each tree part was compared with the total amount of carbon that accumulated in the tree.

Results showed that the stem contained the highest rate of carbon at 62%. The leaves contained the lowest rate of carbon at 2% (Figure 3).

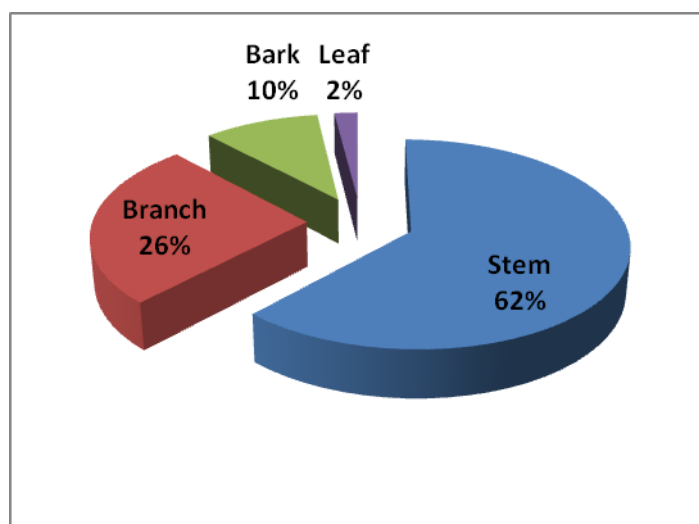


Fig. 3. The average amount of carbon in each tree part as compared to the total amount of carbon accumulated in the tree

Rate of carbon accumulation based on the trees' fresh biomass while considering tree types, tree parts, and diameter.

To assess the changes in the amount of carbon that had accumulated in the tree, factors related to the species and the growth were used as basis. Analysis also included as criterion the percentage of carbon that had accumulated in each tree part. This procedure determined the difference or lack of it in the amount of carbon that had been absorbed.

Results of the analysis of variance (ANOVA) showed that percent rate of carbon is different among the tree parts, and between the tree species. Therefore, when forecasting CO₂ sequestration in the tree, calculation should be done separately for each tree part and tree species.

In reality, however, it is complicated to identify each tree part as the forest tree needs to be cut down first. The tree parts have to be classified, its fresh and dry biomass weighed, and the carbon content in each tree part has to be analyzed. Hence, the research set up the relationship to be forecasted between CO₂ and the other factors.

Moreover, the accumulated carbon content is recognized by species. However, the procedure is difficult to apply in mixed uneven-aged natural forest as there are hundreds of species planted in a hectare. The initial step, therefore, is to get the average amount of carbon in the species.

Relationship between absorbed CO₂ and the factors of the individual tree survey. The

relationship between the absorbed CO₂ by the whole tree and the factors (DBH, H, V, and the tree species) was analyzed by selecting the relative optimal function through the highest relative coefficient at P < 0.05 error. Multivariable function was applied to check the existence of the coefficients based on the criteria similar to P<0.05 error. At the same time, the suitability of the relationship was analyzed.

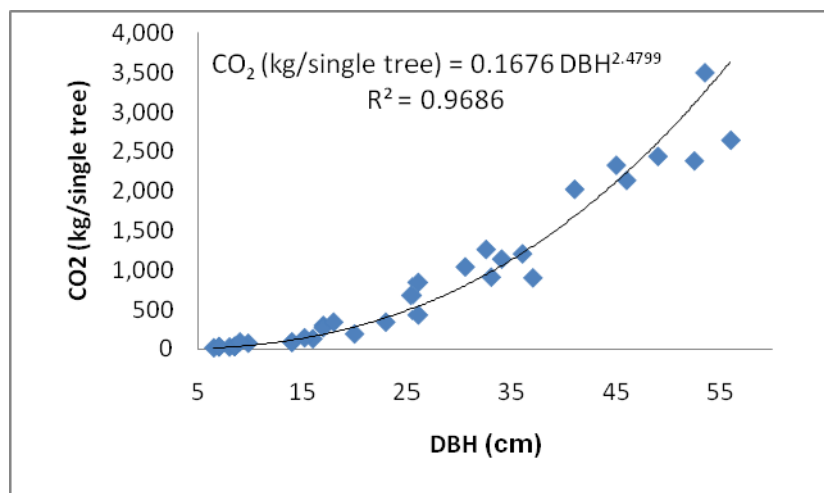


Fig. 4. The relationship model between CO₂ sequestration of single tree and DBH.

Results showed that the firm relationship between CO₂ and the three individual tree survey factors was determined by DBH, H, and V. The multivariable function estimated the amount of CO₂ absorbed in the tree according to DBH (Figure 4).

The relationship between the amount of CO₂ absorbed in each tree part and the individual tree survey criteria was then built up (Table 1).

Table 1. The relationship between the amount of CO₂ in the different tree parts and the individual tree variables.

The relationship functions found in each tree part	R ²	P
ln(CO ₂ stem) (kg/single tree) = 6.15398 + 1.02468*ln(V)	0.971	< 0.05 (1)
ln(CO ₂ bark) (kg/single tree) = 4.11447 + 1.06381*ln(V)	0.936	< 0.05 (2)
ln(CO ₂ branch) (kg/single tree) = -4.11248 + 2.70337*ln(DBH)	0.830	< 0.05 (3)
ln(CO ₂ leaf) (kg/single tree) = -2.941 + 1.72414*ln(DBH)	0.861	< 0.05 (4)

ln(): function of logarithm

The relative error of the two measuring methods for CO₂ was checked.

Results showed that the estimated amount of CO₂ of the whole single tree, through DBH, got an average error of 4.43%. This method can thus be applied in the rapid survey or calculation of many individual trees in a forest.

On the other hand, the estimated amount of CO₂ of the total tree, through the stems, bark, branches, and leaves, showed low error, averaging at 1.38%. This method can be used to accurately estimate the amount of CO₂ absorbed by each tree.

Forecast for CO₂ absorption based on the factors of the forest stand. The amount of CO₂ absorbed in each unit area of forest needs to be quantified. This is necessary in assessing the economic value of the environmental service.

To carry out this process, CO₂ was withdrawn from the samples and calculated for each tree. Calculations were based on estimates obtained for the individual tree or for each tree part, whichever was more accurate.

In many cases, however, the amount of CO₂ absorbed in the forest stand needs to be immediately appraised to calculate the environmental value. At the same time, appraisal is needed to supervise CO₂ accumulation over time and on a large scale.

The research looked into the relationship between the total amount of absorbed CO₂ per hectare, and the factors of the forest stand survey. Through a multiregression analysis, the following equation was obtained:

$$\text{CO}_2 \text{ (kg/ha)} = - 53242.2 + 11508.035 \text{ BA (m}^2\text{/ha)} \quad (5)$$

with R² = 0.987, P < 0.05

This equation showed that the amount of CO₂ absorbed in each forest stand was identified. This equation can be used as basis in calculating the environmental service fee on a large scale. The mathematical model also showed that the absorbed amount of CO₂ per hectare changed according to the biomass on the ground, as represented by the total BA.

These results showed that forecasting the amount of carbon or CO₂ absorbed in the woody vegetation in the forest can be done through a process as shown in Figure 5.

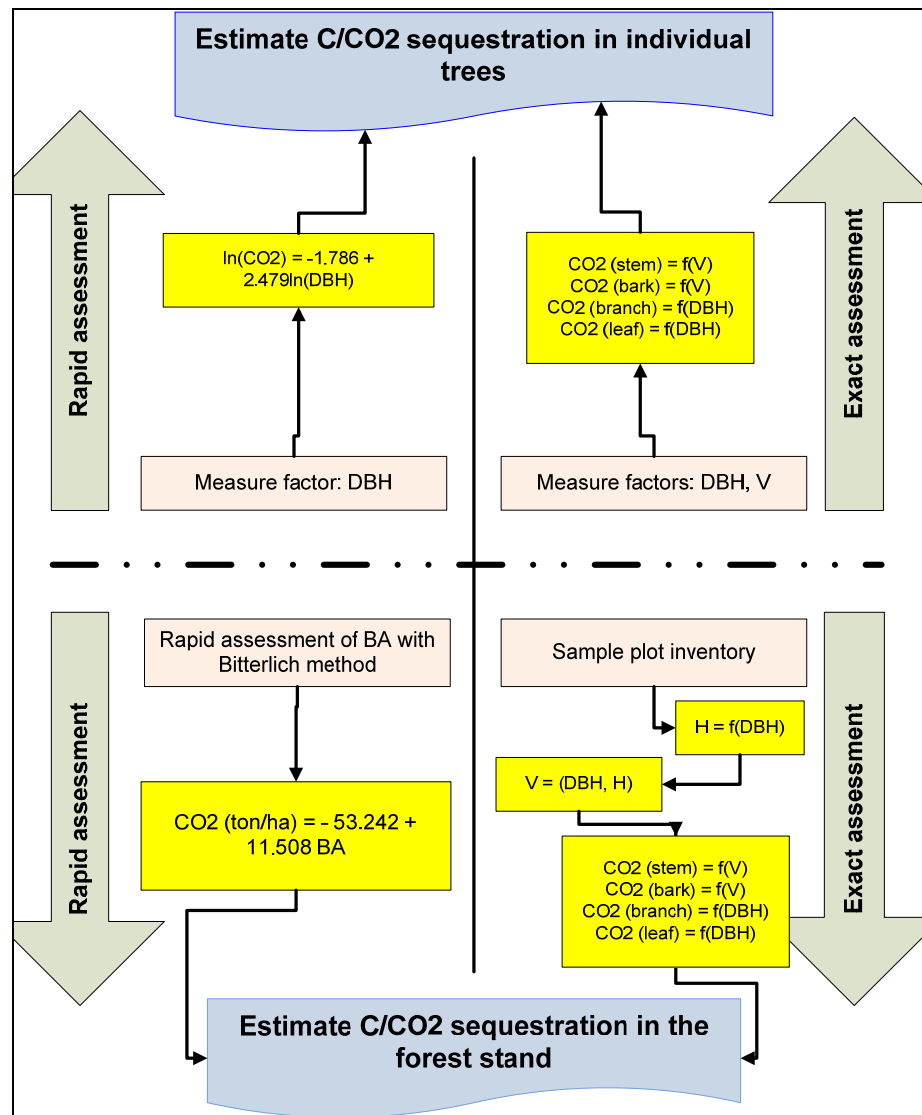


Fig. 5. Diagram showing the forecasting process of CO₂ absorption in individual tree and forest stand.

Quantification of CO₂ sequestration in the forest stand and its value for environment

service. The amount of CO₂ absorbed in the forest every year can be calculated through the mathematical equation $CO_2 \text{ (ton/ha)} = -53.242 + 11.508 \text{ BA (m}^2\text{/ha)}$. If BA was measured twice, during A and A+1 years, or based on the annual increment of BA, the yearly increase of CO₂ sequestration can be forecasted. .

The forecasting results showed that if forest management would be effective, the yearly absorption of CO₂ could reach 1.73-5.18 t/ha/yr. The yearly value of accumulated CO₂ per ha was calculated through the yearly amount of CO₂ absorbed, and multiplied by US\$20 per ton of CO₂ (medium cost).

Results showed that carbon sequestration was valued at US\$35-100/ha/yr. This amount can be considered valuable for forest managers and the indigenous communities who are protecting and managing the forests (Table 2).

Table 2. The predicted economic values of the amount of CO₂ absorbed according to forest status.

Forest status	BA (m ² /ha) at time A year	BA (m ² /ha) at A+1 year corresponding to grow per year 1.5%/year	Yearly absorbed CO ₂ (ton/ha)	Price (USD/ton CO ₂)	Yearly Accumulative value CO ₂ year/ha (USD)
Young	10	10.15	1.73	20	35
Poor	20	20.30	3.45	20	70
Medium	30	30.45	5.18	20	100

Conclusions

From the above mentioned results, the research concluded that:

- Absorption of carbon was different for the whole tree and its parts. Hence, accumulated carbon should be calculated first according to tree type. Moreover, calculations of carbon sequestration were found complicated as they depended on tree species.
- The ability of the tree to sequester CO₂ could be estimated using the mathematical equation: CO₂ (kg/single tree) = 0.1676 DBH(cm)^{2.4799}. It could also be estimated using regression analyses for each tree part.
- By using the regression method, the amount of CO₂ absorbed per hectare was found related to BA through the equation: CO₂ (ton/ha) = - 53.242 + 11.508BA (m²/ha). Through this equation, the yearly accumulation of CO₂ was forecasted to gain from 1.73-5.18 ton/ha/yr depending on the status of the evergreen forests.

Absorbed CO₂ capacity was equivalent to US\$35-100 per hectare per year depending on the forest status, and forest resource base through BA. This can be used to calculate the potential environmental service payment. This can help determine the beneficial sources of income which is very meaningful for forest managers, or the indigenous peoples who are at the forefront of forest management at the local level.

Recommendations

This research therefore recommends the following:

- More studies to appraise the CO₂ absorptive capacity of trees, and its equivalent environmental fees;
 - Development of an environmental fee payment mechanism or policies for CO₂ sequestration of natural forests;
 - Application of research results on a large-scale to further identify CO₂ absorptive capacity through the identified forest stand factors; and
 - More studies on the application of the research results to other forest types of different status in the other highland areas of Vietnam.
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