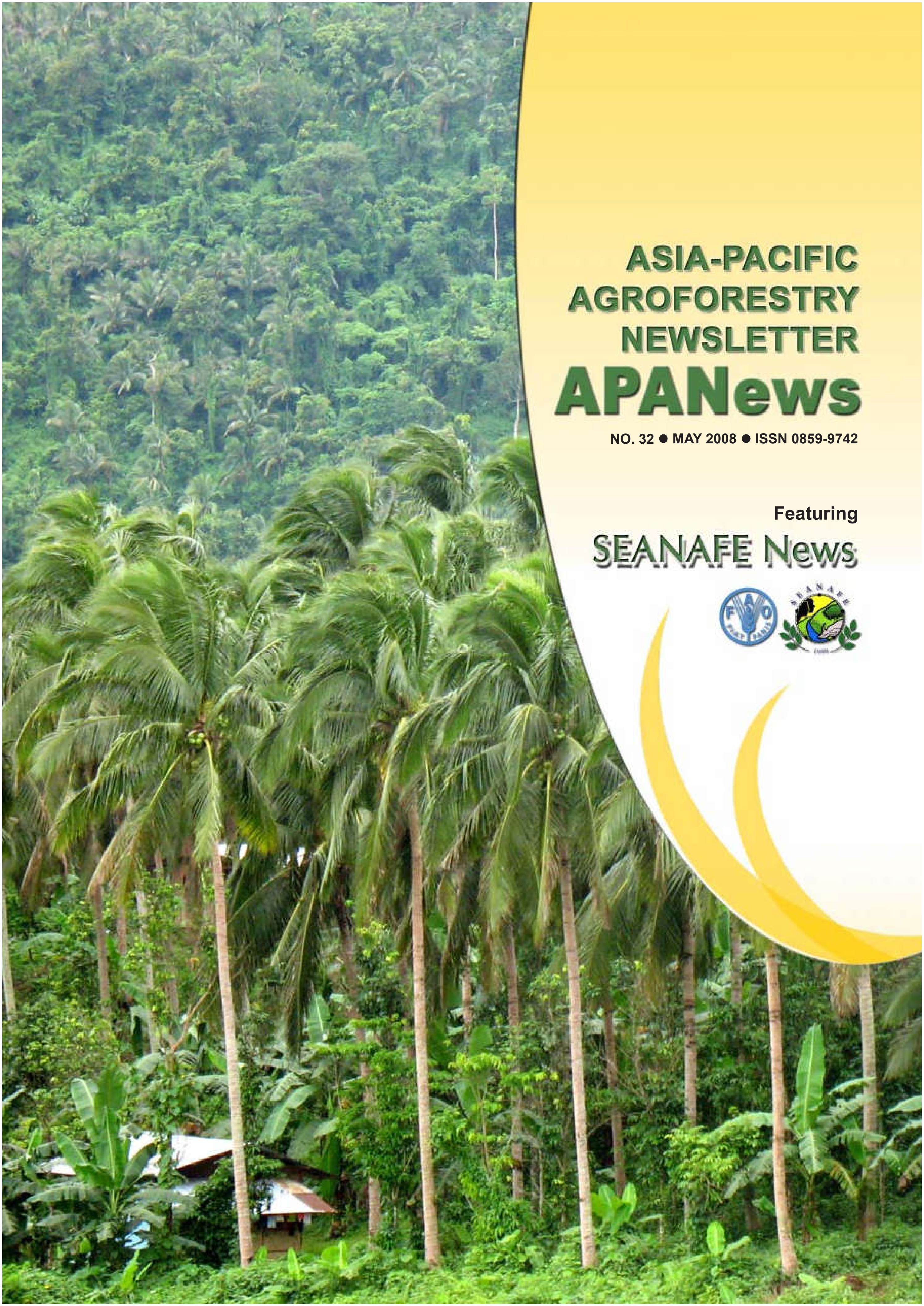

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Featuring

SEANAFE News

times a year, depending on the age of the stands. Fruiting was avoided, and the branches were removed at pencil diameter.

Results showed that K-29 and K-8 sources produced fodder in good quantities, as compared to the other introduced species/strains, under rainfed conditions. The protein content was also high in K-29. However, the anti-quality parameters (mimosine and tannins), which were very important requirements for good quality fodder, were found to be minimal in K-743A (*L. leucocephala x L. diversifolia*).

The fodder crop productivity in the *subabul* alleys was not affected. The aboveground biomass of the system was higher than in the area solely planted with annual and perennial crops (napier bajra hybrid, maize + cowpea, followed by berseem + ryegrass) for fodder production.

The *subabul*-based pasture production system was found to be highly productive as it yielded 35.25 g/ha of fuelwood. This is in addition to fodder from intercultivated crops and *subabul*. The biomass yield of one hectare of intercultivation is equivalent to approximately 1.45 hectares planted solely with fodder crops.

Subabul-based fodder inter-cultivation produced approximately 15 percent higher protein than the area planted solely with fodder crops on a unit area basis.

Analyzing nutritive contents

The anti-nutritive factors assume greater significance when tree leaves are major components of the diet. Although *subabul* contains an array of secondary plant metabolites, the major compounds that affect the nutritive value are the non-protein amino acids, mimosine and tannins.

The mimosine content in the fodder can be diluted to a greater extent by selecting the appropriate *subabul* source, and mixing the intercultivated fodder, at the ratio of 1:2 to 1:3. As a rule, no more than 30 to 50 percent *subabul* in the diet should be given as feed to achieve optimum productivity of cattle, sheep and goats.

Subabul leaves can also be used to increase the protein content and nutritive value of silage. ■ *The authors are affliated with the Punjab Agricultural University, Ludhiana (India) - 141 00.*

Estimating CO_2 sequestration in natural broad-leaved evergreen forests in Vietnam

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The increase of carbon dioxide (CO_2) in the atmosphere is becoming a global concern. The amount of CO_2 sequestration depends on forest type, forest status, dominant tree species and forest stand age.

Researches on CO_2 sequestration of each specific forest type are needed to quantify the economic value of forests, and develop payment mechanisms for environmental services.

This is the focus of the Master of Science thesis titled 'Forecasting CO_2 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).

Objectives and hypotheses

The research aimed to contribute to the development and application of estimating CO_2 sequestration in natural forests. Results will contribute to the development of mechanisms to determine economic values of forests, and payments for environmental services.

The research first defined CO_2 sequestration for woody vegetation and its other sections above ground, and set its objectives to:

- estimate the CO_2 absorbing capacity of individual forest trees and the forest stand; and
- estimate economic values based on the CO_2 sequestration capacity of the natural evergreen forests of different conditions.

The research was carried out with the hypotheses that:

1) there is considerable difference in the CO_2 absorbing capacity of forests according to forest conditions and stand age; and
2) it is possible to calculate the CO_2 stock as basis for environmental service fees.

Scope and limitations

The research was limited to:

- natural broad-leaved evergreen forests, which were further classified into "young", "poor" and "medium" forests;
- targeting stems, bark, branches and leaves of the trees with

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- diameter of 10 cm or more in measuring CO_2 absorbing capacity of woody vegetation; and
- the study site of 74 573 ha of natural forests in 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 CO_2. 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 used to determine the amount of CO_2 that had been absorbed. The results were then used to determine the CO_2 absorbing capacity of the forest trees and forest stands.

Subsamples were taken and analyzed to measure the carbon stock in the different wood parts of the trees. A mathematical model was then used to quantify the CO_2 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 stock in plants with DBH (diameter at breast height) > 30 cm. Subsample plots, measuring 5 m x 40 m, were also established to calculate the carbon stock in plants with 5 cm < DBH > 30 cm.

The sample sites were established under three forest conditions classified as: i) young forest restored after cultivation ('young'); ii) highly harvested forest ('poor'); and iii) lightly disturbed forest ('medium').

Analysis was carried out in two sample plots for each of the three forest classifications of young, poor and medium forests.

The stems, bark, branches and leaves were weighed and measured for total fresh biomass. A subsample of one kilogram per part was taken from each part of the tree.

Analyzing subsamples for CO_2 content:
34 trees were analyzed, from which 136 subsamples were obtained. The different tree parts (stems, bark, branches and leaves) were then analyzed based on the criteria of ratio of dry substances, mineral, ash and carbon. (The analysis was carried out at the Biological Botany Laboratory, Agricultural and Forestry Department, Tay Nguyen University.)

Analyzing the biomass and tree-diameter relationship:
The fresh and dry biomass of each tree part was calculated. The relationship between the fresh and dry biomass and tree diameter was then determined to select the appropriate function.

Analyzing the rate of CO_2 accumulation in trees:
The rate of CO_2 accumulation in trees was analyzed based on the relationship between CO_2 and fresh biomass, and the selected optimal function.

The one-factor variance model was used to evaluate the differences in the carbon stock based on the fresh biomass of the trees, tree parts, and tree diameter.

Estimating CO_2 absorption in forest trees, and forecasting for forest stand:
A mathematical model was used to analyze the CO_2 absorptive capacity of the trees and forest stands. The model used was based on the following:

- the dependent variable *y* signifies the amount of CO_2 in forest trees or the CO_2 per hectare of a forest stand;
- the independent variable *xi* includes the forest variables DBH, H (height), V (volume), BA (basal area), M (stand volume per ha), and N (density); 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 per each tree part. The rate of carbon accumulation per each tree part was analyzed by comparing carbon accumulation rates per each part with the total amount of carbon accumulated in the tree.

Results indicate that the stem part contained the highest rate of carbon at 62 percent. The leaves contained the lowest rate of carbon at two percent (Figure 1).

Rate of carbon accumulation based on the fresh biomass per tree type, tree parts, and diameter:
The amount of accumulated carbon in the tree was assessed based on species and growth, and further analyzed against the percentage of carbon that had accumulated in each tree part. This procedure determined the amount of carbon that had been absorbed.

Results of the analysis of variance (ANOVA) indicated that the rate of carbon absorption is different among the tree parts, and tree species. Therefore, when estimating CO_2 sequestration, calculations should be done separately for each tree part and tree species. Hence, the research looked into the relationship between the CO_2 sequestration capacity of tree parts 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, prompting the calculation of the average amount of carbon in the species.

Relationship between absorbed CO_2 and the factors of the individual tree survey:
The relationship between the CO_2 absorbed 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. The multivariable function was applied to check the existence of the coefficients based on the criteria similar to $P < 0.05$ error.

Results confirmed that a relationship between CO_2 and the three individual tree survey factors is determined by D, H and V. The multivariable function estimated the amount of CO_2 absorbed in the tree according to DBH (Figure 2).

The relationship between the amount of CO_2 absorbed in each tree part and the individual tree survey criteria was then developed (Table 1).

The relative error for the estimated amount of CO_2 of the whole tree (at DBH), had an average error of 4.43 percent. Thus, this method can be applied to calculate many individual trees in a forest.

On the other hand, the estimated amount of CO_2 of the total tree, through the stems, bark, branches and leaves, had low error, averaging 1.38 percent. Thus, this method can be used to accurately estimate the amount of CO_2 absorbed by each tree.

Quantifying CO_2 absorption based on forest stand factors:
In order to assess the economic value of the environmental services, the amount of CO_2 absorbed in each unit area of forest requires quantification.

To carry out this process, CO_2 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 CO_2 absorbed in the forest stand needs to be immediately assessed to calculate the environmental value. At the same time, assessment of CO_2 accumulation is necessary over time and on a large scale.

The research looked into the relationship between the total amount of absorbed CO_2 per hectare, and the factors of the forest stand survey. Through a multiregression analysis, the following equation was obtained:

CO_2/ha (kg) = - 53242.2 + 11508.035 BA (m^2/ha)(5) with $R^2 = 0.987$, $P < 0.05$

This equation indicates that the amount of CO_2 absorbed in each forest stand was identified. This equation can be used as the basis in calculating the environmental service fee on a large scale.

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Table 1. The relationship between the amount of CO_2 in the different tree parts and the individual tree variables.

Relative functions found	R^2	P	
ln (CO_2 stem) = 6.15398 + 1.02468*ln(V)	0.971	<0.05	(1)
ln (CO_2 bark) = 4.11447 + 1.06381*ln(V)	0.936	<0.05	(2)
ln (CO_2 branch) = -4.11248 + 2.70337*ln(D)	0.830	<0.05	(3)
ln (CO_2 leaf) = -2.941 + 1.72414*ln(D)	0.861	< 0.05	(4)

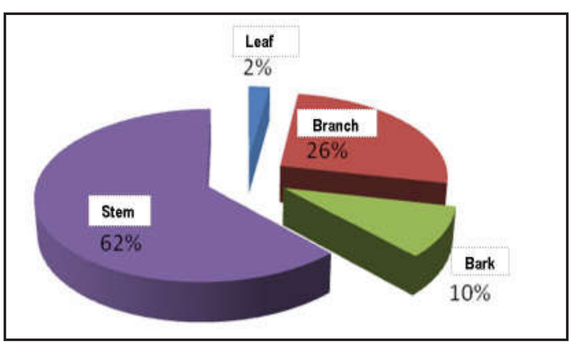

Fig. 1. The average amount of carbon in each tree part as compared to the total amount of carbon accumulated in the tree.

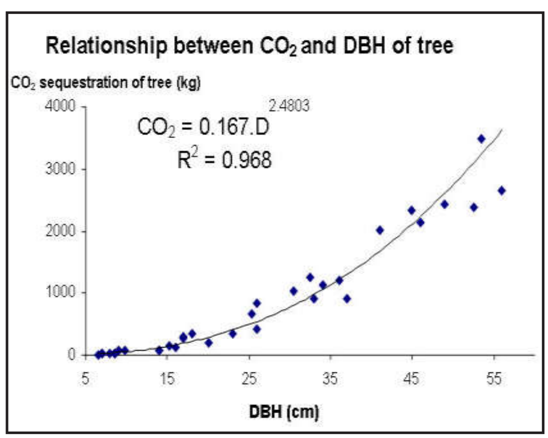

Fig. 2. The relationship model between CO_2 sequestration of the tree and DBH.

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The mathematical model also shows that the absorbed amount of CO_2 per hectare changes according to the biomass on the ground, as represented by total BA.

These results indicate that estimating the amount of carbon or CO_2 absorbed in the woody vegetation in the forest can be done through a process as shown in Figure 3.

Quantification of CO_2 sequestration in forest stands and its value for environmental services:
The amount of CO_2 sequestered in forest stands annually can be calculated through the mathematical equation CO_2 (ton/ha) = - 53.242 + 11.508 BA (m^2/ha). If BA is measured twice, once in year A and once in year A+1, or based on the annual increment of BA, the yearly increase of CO_2 sequestration can be estimated.

The results show that if forest management were effective, the yearly absorption of CO_2 could reach 1.73 to 5.18 ton per hectare per year.

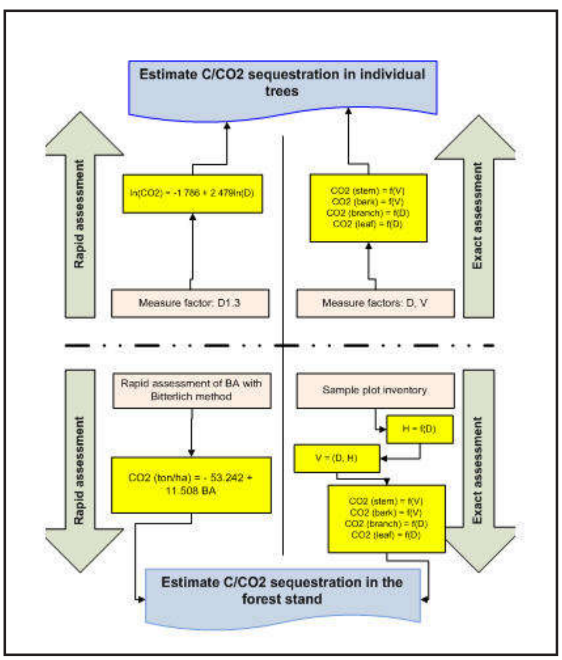

Fig. 3. Forecasting process of CO2 absorption in individual tree and forest stand.

The yearly value of accumulated CO_2 per hectare is calculated through the yearly amount of CO_2 absorbed, and multiplied by US$20 per ton of CO_2 (medium cost).

Results indicate that carbon sequestration is valued from US$35 to US$100 per hectare per year. This is considered a substantial amount for forest managers and indigenous communities who are protecting and managing the forests (Table 2).

Conclusions

From the above-mentioned results, the research concluded that:

- Absorption of carbon is determined by forest conditions, tree part and tree species. Hence, carbon stock should be calculated first according to the forest condition. Moreover, calculations of CO_2 sequestration are complicated as they depend on the tree species.
- The ability of the tree to sequester CO_2 could be estimated using the mathematical equation: DBH ($\ln(CO_2)$ = -1.78618 + 2.4799. It could also be estimated using regression analyses for each tree part.
- By using the regression method, the amount of CO_2 absorbed per hectare was found related to BA through the equation: CO_2/ha (ton) = - 53.242 + 11.508BA (m^2/ha). Through this equation, the yearly accumulation of CO_2 is estimated to gain between 1.73 and 5.18 per tons per hectare per year, depending on the status of the forests.

Absorbed CO_2 capacity is valued at US$35 to 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:

- Carry out studies to look into the CO_2 absorptive capacity of trees, and its environmental service payments;
- Development of an environmental fee payment mechanism or policies for CO_2 sequestration of natural forests;
- Application of research results on a large scale to further identify CO_2 absorptive capacity through the identified forest stand factors; and
- Carry out studies to explore the application of the above research results to other forest types of different status in the other highland areas of Vietnam.■

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Table 2. The predicted economic values of the amount of CO_2 absorbed according to forest status.

BA (m^2/ha) at time A+1yr corresponding to grow per year 1.5/year	Yearly absorbed CO_2 (ton/ha)	Price (USD/ton CO_2)	Yearly absorbed CO_2 year/ha (US$)
10.15	1.73	20	35
20.3	3.45	20	70
30.45	5.18	20	100