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CO_2 SEQUESTRATION ESTIMATION FOR THE LITSEA-CASSAVA AGROFORESTRY MODEL IN MANG YANG DISTRICT, GIA LAI PROVINCE IN THE CENTRAL HIGHLANDS OF VIETNAM

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On behalf of research team

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LIST OF ABBREVIATIONS

- CDM: Clean Development Mechanism
- CFEE: Center of Forest Ecology and Environment
- ICRAF: World Agroforestry Center
- REDD: Reducing Emissions from Deforestation and Degradation.
- SEANAFE: Southeast Asian Network for Agroforestry Education.
- VNAFE: Vietnam Network for Agroforestry Education

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1 RATIONALE AND OBJECTIVES

1.1 Research rationale

The practice of agroforestry has increasingly been recognized worldwide as bringing not only economic aspects into land use, but also satisfying the requirements of environmental sustainability, e.g. soil protection and improvement, water holding capacity, CO_2 absorption and sequestration in the system, reduction of greenhouse effects, and a contribution to climate change mitigation.

The results of this research serve as the initial point for future research on the environmental service value of agroforestry models, which concentrate on the capacity for CO_2 sequestration of forest trees, such as *Litsea glutinosa,* in the model. Moreover, this research indicates the role of agroforestry as a contributing factor in global climate change adaptation and mitigation processes and orients the promotion of agroforestry not only for economic reasons, but also for environmental services, including the reduction of carbon emissions.

In the Central Highlands of Vietnam, most cultivated lands are on steep terrain; therefore, mono-cultivation may result in many threats to the sustainability of the environment. In many locations in Vietnam, farmers are aware of these problems and thus, adopt agroforestry models for their cultivated land. In these models, annual crops are a traditional species, such as rice, maize, cassava, and beans, while a number of indigenous forest species have been intercropped, thus enhancing the diversity of the agroforestry models. One of these models is the *Litsea glutinosa*–Cassava (Litsea-Cassava) agroforestry model. *Litsea* is an indigenous, multi-purpose, green broadleaved species found mostly in semi-deciduous forest in the Central Highlands of Vietnam. Most of its biomass (stem, bark, leaves, and branches) can be used or sold in the market to produce different products. *Litsea* is usually planted in agroforestry models together with annual crops such as cassava, rice, and coffee.

The Litsea-Cassava agroforestry model has been popularly practiced in the communes of Mang Yang district, Gia Lai province, producing a stable volume and contributing significantly to household income. This model overcomes the shortcomings of mono-cultivation of cassava on land under shifting cultivation. Mono-cultivation of cassava results in the land becoming exhausted after three-to-four years, and so *Litsea* helps to improve land use by supporting a relatively sustainable mode, and creating stable income for farmers. In addition, according to many cycles, the model helps store carbon; therefore, it is significant in reducing the greenhouse effect, which has become a global concern in recent years.

Hence, it is necessary to research the capacity of the Litsea–Cassava agroforestry model to store carbon and generate the necessary database and information. The research results can create a basis for the dissemination and promotion of payment for environmental services in the agroforestry model.

1.2 Research objectives

The research aimed to:

i) Construct a model for biomass estimation and CO_2 sequestration of *Litsea plutinosa* in the Litsea–Cassava agroforestry model.
ii) Define the amount of absorbed CO_2 and its environmental values in the Litsea–Cassava agroforestry model.

2 LITERATURE REVIEW

CO_2 sequestration in forest trees, stands and agroforestry

Because of the importance of carbon pools in tropical forests and in agroforestry systems in recent decades, many organizations around the world have carried out studies in forest ecology related to forest biomass and carbon storage. The methodology, as well as the policy mechanism, has aimed at the protection of tropical forests and sustainable land use due to the importance of environmental values in global climate change.

Research on monitoring forest cover change, carbon storage and policy in order to implement the REDD program has been requested by the Center for International Forestry Research (CIFOR) (2007). The World Agroforestry Center (ICRAF) (2007) developed methods for the rapid forecast of carbon storage through monitoring land use change using remote sensing and sample plots. These methods can be suitably applied in Vietnam, depending on existing ecological systems.

Wageningen University in the Netherlands developed Co2Fix V3.1 software to calculate biomass and carbon storage in forests. In fact, this software produces synthetic data on biomass and carbon storage based on suitable input information, such as volume, growth, biomass, initial carbon storage, and forest age. Since event age and forest species are the main input data in this study, the software is not suitable for use in studies of the ecological systems of Vietnam. However, attention should be given to developing the software in order to obtain biomass data and carbon storage in moist tropical forests.

In general, the estimation of carbon stored in forest plants is based on inventory data, such as individual tree and standing volume. The tree biomass and carbon storage are calculated from the standing volume. Empirical or theoretical models have been used to estimate carbon in different components of the forest's ecological system, such as living and dead trees, or underground [1] [12], [15]. Some studies defined carbon content in terms of the dry biomass by multiplying dry biomass by a factor of 0.5 [1], [21], [25]. In research on carbon storage in a pulpwood plantation, Pirard (2005) calculated the amount of stored carbon based on the total fresh living mass above ground and then defined the dry living mass (without moisture) by multiplying the total fresh living mass by a factor of 0.49 before finally multiplying the dry living mass by a factor of 0.5 to define the amount of carbon stored in trees .

In order to calculate the amount of carbon stored in a tree, Smith *et al*. (2002) measured all trees in sample plots, but the sample trees were divided into different parts. The biomass of each part was calculated using a growth model for each individual species. In certain species, where modeling regression was not available, models for neighboring species were applied. The research indicated that ratio of carbon in individual components was: branches, 5,9± 0.4%; stems, 33.8 ± 1.7%; and bark, 5.1 ± 1.4%. According to Gann (2003), the carbon pool should include the components of trees such as leaves, stems, branches, and roots; nevertheless practical conditions as well as cost should be considered.

Carbon estimates in forest trees or stands are usually calculated based on predicting dry-weight biomass in tons per hectare in different growth periods. CO_2 concentrations in organic matter are directly calculated thereafter. Alternatively, carbon (C) pools can be estimated by assuming they are 50% of the dry-weigh biomass and then inferring CO_2 concentrations [1].

In Vietnam, there has not been any complete research on forest biomass and carbon storage in natural forests and agroforestry models, which provide the basis for evaluating environmental services for forest types and different agroforestry models with respect to CO_2.

Nguyen Ngoc Lung (1989) provided the first study on forest biomass for a pine forest in Lam Dong province. The modeling method he developed was based on inventory data and forest monitoring.

The Center of Forest Ecology and Environment (CFEE) of the Institute of Vietnamese Forestry Science (FSIV) defined the carbon pools of bush vegetation, corresponding to IA and IB in the classification system for Vietnamese forests. This provided a carbon baseline for plantation projects according to the Clean Development Mechanism (CDM). In this study, fresh- and dry-biomass were determined for the individual components of stems, branches, and leaves. The carbon pools were specified using dry biomass and a transformation parameter of 0.5. However, the study calculated stored carbon, which was estimated through the transformation coefficient, but carbon pools in individual components were not separately analyzed [31].

With respect to research on the carbon concentration in plantation forests, CFEE, through its forest assessment research, estimated carbon using the diameter at breast height for five species: *Acacia mangium*, *Acacia. auriculiformis, Acacia hybrid, Pinus assoniana* and *Pinus merkusii* [31]. Vo Dai Hai (2009) established relationships between the amount of carbon and the measurable factors of an average tree to predict the stored carbon in an eucalypt plantation.

Bao Huy, Pham Tuan Anh (2008) with financial support from ICRAF/SEANAFE, in research conducted in the Central Highlands of Vietnam, attempted to predict the capacity for CO_2

absorption in a natural broad-leaved evergreen forest. They developed an analytical method for aboveground stored carbon in woody forest trees and for the stand based on separate components, such as the stem, bark, leaves and branches. They also estimated the CO_2 concentration in forest trees and stands. Based on this study, Bao Huy (2009) continued to develop a methodology for carbon pool estimation in Vietnam's natural forest ecological systems.

Cost of environmental services of CO_2 absorption from forests and agroforestry:
Among various environmental services that highland communities may be compensated for (e.g. carbon absorption, watershed protection and biodiversity conservation), the compensation mechanism for the carbon market may provide the highest income; carbon forests are considered as an important contribution to poverty alleviation [21]. Compensation plans have increased rapidly, with Smith and Scherr (2002) believing that there is livelihood potential based on carbon forest projects. The Carbon Forest was established on this basis.

The Carbon Forest is forest that has as its primary objective the aim of regulation and storage of carbon flux from industrial activities. The concept of a Carbon Forest is usually associated with projects that aim to improve the standard of living of the people who live in and close to the forest. These people are responsible for forest protection but are being impacted by global climate change. Therefore, they must be compensated or paid a suitable amount. This will improve their livelihood and simultaneously protect the sustainability of the environment for the future. In other words, activities, which aim at storing carbon and are based on participation by communities, can only be successful if there is a clear mechanism to maintain and protect stored carbon that is connected closely with the livelihood of the people who live close to the forest and use forest land.

The mechanism for a carbon market is still being debated. The CDM programs and the concept of REDD in very recent times have only been developed to the stage of a conceptual framework and approach. Several experiments have been promoted in some locations. Forest protection and agroforestry model development are appropriate strategies to balance a variety of gas emissions, which cause the greenhouse effect. Simultaneously, countries around the world are developing compensation agreements and payments to communities in developing countries to protect forests and store CO_2 accordingly in the forests and in other types of land use in tropical areas. [13]

Discussion:
From the literature review, the problems related to this study are:

- Estimates of stored carbon in forest trees have been investigated in previous studies under different forest ecologies, such as boreal, temperate, tropical forest, and plantation forest. The main methods have been based on sample plots, defining biomass, and relationships to estimate the dry biomass of different forest attributes. Carbon was predicted using a factor of 50% of dry biomass. The shortcoming of these methods is that carbon has not been estimated directly; the conversion of C = 50% of dry biomass seems not to be precise. Most of the earlier studies ended up estimating the carbon stored in individual trees without a consideration of the stand, especially in mixed and uneven rainforests.

- In Vietnam, research on carbon sequestration has only been carried out in several main types of mono-plantation. Although agroforestry is one land use type that is more sustainable, there has not been any attention paid to the appraisal of the environmental significance of such a model.
- Payment for environmental service related to CO_2 absorption in a plantation forest has been recognized by the CDM program. However, on the other hand, the reduction in the loss of natural forest areas, through payments to reduce carbon dioxide gas emission from cutting down and degrading the natural forest have been promoted by REDD programs. However, agroforestry, which aims to harmonize the economic and environmental profits, has not been taken into account to estimate values in CO_2 emission mitigation.

Therefore, it has been necessary to research thoroughly the following relevant problems:

- Methods to estimate biomass and carbon stored in agroforestry systems.
- Quantification of the service value of CO_2 concentration in agroforestry models and the promotion of a payment mechanism to enhance the community's perception of and responsibility for sustainable land use and management to obtain multiple outcomes.

3 OBJECTIVE AND SITE STUDY CONDITIONS

3.1 Research objective

i) **The structure of the agroforestry model**

The model investigated involved the species *Litsea glutinosa* (Litsea) and *Cassava*. Data associated with the techniques in the field are:

Litsea glutinosa:

- Age: from 1 to 7 years
- Cycle period: period 1 (seed) to periods 2 and 3 (shoots)
- Density: Varying from 500 to 2000 trees/ha
- Number of shoots/stump in periods 2 and 3: 1-5 shoots

Agroforestry model of Lisea-Cassava in the study site

Cassava (*Manihot esculenta* Crantx) was intercropped between every second row of Litsea. The cover rate of cassava was modified according to the density and age of the

Litsea. Where Litsea had been planted at low density and had a young age, the cover of cassava was denser. Hence, the cassava cover varied from 15 to 80% of the total area in the agroforestry model.

ii) **Absorption and CO_2 concentrations**

The model only considered biomass and CO_2 absorption of Litsea; only stored carbon in components above ground (stem, bark, leaves and branches) was estimated. The changes associated with density, age, and business periods were considered in this study.

iii) **Characteristics of the two species in the agroforestry model**

- ***Litsea glutinosa***, synonym: *Sebifera glutinosa*, *Litsea sebifera* belongs to the *Lauraceae* family.

·lutinosa

Morphology: Litsea is a medium woody tree, evergreen, 20-25 m high, normally 20-30 cm in diameter, possibly reaching 40 cm in some cases. It has a round stem and straight, small branches, with early branch partition. The outer bark is white-gray in color, the outer skin is unclear and the inner bark is a slight yellow color and has an aroma. It has a simple leaf structure. The leaf is 12-13 cm long, 3-4 cm wide, with a sharp head and a wedge-shaped leaf stem, with two flat faces. It produces yellow flowers in October and November. Its fruit has a diameter of 10-15 mm. One kilogram of fruit contains about 3200-3400 seeds.

Ecology and cultivation technique: Litsea trees are usually found in secondary forest or regeneration after agriculture at elevations below 1000 m a.s.l. Its distribution covers the midland mountain provinces from Sơn La, Lạng Sơn, Bac Giang, Thua Thien-Hue, Gia Lai, to Dak Lak. It has adapted to regions having an annual average temperature of 22-27^{o}C, a maximum air temperature from 32 to 34^{o}C, with an average temperature from 10 to 15^{o}C, and an annual average rainfall of 1500-2500 mm. Litsea grows well on feralit soils developed on basalt-bedrock or clay. It is suited to humid conditions, usually growing on slopes less than 25^o in soils more than 50 cm deep, with a pH from 4 to 5. Litsea's distribution ranges between latitudes 8 to 22^o north. Although humid conditions are preferred, an average light regime is required.

Average levels of growth are observed during the early stages.

Litsea is a light preferring species, and grows rapidly. It can readily regenerate from seed and has strong coppicing ability. Litsea can be planted using several methods: from shoots from a mother tree; from seedlings collected from the forest; by scattering seeds; or by germinating seeds in a box. It is now grown in many Asian countries, as well as in Australia, New Zealand, and in North and South America.

Under natural conditions, Litsea cohabits with several light-preferring, broadleaved species, including *Quercus*, *Eugenia*, *Vitex*, and *Pterocarpus*. This implies that Litsea can be inter-cultivated with other light-preferring, broadleaved species in order to benefit from shade protection during early growth.

Litsea trees have been cultivated since 1991 by famers of the Gia Lai and Kon Tum provinces. They have been planted around houses and in old cultivated fields. They also are cultivated in several districts of Mang Yang, Chu Pa, Chư P'rong (Gia Lai).

Tran Van Con (2001) suggested that Litsea trees should be planted in a variety of main strata of reddish-brown soils under bush vegetation, on flat terrain and in relatively humid areas. They also can be cultivated under bush vegetation having grey-red soils, on flat highlands, and hot, dry conditions. As a plantation species, Litsea could be mixed with other species (inter-cultivation) or included in agroforestry regimes. Stocking mix rates of 60% and 40% of Litsea and fruit trees, respectively are used, with the Litsea planted either in mixed rows or in clusters. The distance between rows is 3 m and between trees is 3 m.

Uses: Litsea is a multi-purpose species. Its bark contains aromatic oil, which can be extracted for making medicine, perfume, industrial glue, and paint. In addition, it is used to produce incense for religious practices. Litsea's wood has a yellowish-brown color, is hard and termite-free. The wood can be used for furniture, pulpwood or fuel, while the leaves can be used for domestic food (Le Van Minh, 1996).

In India, a substance from the bark of Red Litsea called Sufoof-e musummin, which is employed in medicines. In Indonesia, a spectrum technique to extract several substances from the branches, roots and bark of Litsea, including 2,9 dihydroxy, 1,10 dimethoxyaporhine, and 6 methoxyphenan threne 9% which are used in medicine. At an international conference on folk medicine and medicinal trees held in Indonesia in1990, it was confirmed that several chemical substances extracted from Litsea could be used to make medicines. Thus, it can be clearly seen that Litsea has an economic value, especially for medicinal use.

The book, "Popular vegetables in Vietnam" describes Litsea along with its uses, such as applying bark to reduce pain, or for disease treatments. Litsea fruit contains 45% fat in its wax, which includes substantial amounts of laurin and olein that are used in candle and soap production. Litsea is used to make paper, while the leaves provide fodder for buffalos and cows. The bark of the main trunk contains glue substances and a little oil, which can be used for glue, in paper making, as an additive in concrete, and for incense production. The bark can be beaten to cover swollen wounds or burns and to treat intestinal diseases and dysentery. Litsea bark soaked in water is also used as hair oil.

- **Cassava**. Scientific name *Manihot esculenta* Crantx, a member of the Euphorbiaceae family.

Cassava trees were first recorded being used in middle-American countries, such as Colombia and Venezuela around 3000 BC. Later, cassava was transported by the Portuguese and planted in Africa and then in Asian countries. The bulb of cassava contains a large amount of starch, which is used as a main food source by about 10% of the world's population. According to the International Centre of Tropical Agriculture (CIAT), there are about 1.9 million ha of cassava planted in Asia, most of which is found in Thailand, Indonesia, India, North China and Vietnam. In many regions, the rapid increase in cassava areas is a response to the need for animal food.

Morphology: Cassava has a small stem, around 1.5 to 3 m high. The main harvested component is the bulb, which is from 40 to 60cm in length. The bulb contains a lot of starch that is used for food and as a source for the sodium glutamate industry. Cassava has white latex, with unsexed flowers in the same flower stump; the flowers rise in a cluster at the top of the tree.

At present, in Vietnam, there are many cassava species. The two most popular species are: a) *San phat, san tay, san hong lai* characterized by a slight-pink, long section, dark green leaves, red inner bark and a bulb that becomes starchy if well-cooked; and b) *San du* or domestic cassava which has a short height, a slightly green young top, and a leaf base that is slightly red. The outer bark of the bulb is dark grey, while the inner bark is white and contains a lot of water. This type often has a high productivity.

Physiology, ecology and technology: Cassava species are suited to a tropical climate. However, its productivity depends mainly on the genus, fertility and soil moisture. Cassava is highly drought-tolerant and strongly heliophilous, adapting to locations up to an elevation of 800m, and rainfall in the range from 750 to 2500 mm/year. Sustainable cropping of cassava, requires maintaining the fertility of the soil, taking into account organic fertilizer, especially with regard to the agroforestry model, where perennial crops can improve the soil. Cassava is often cultivated in different types of soil. It can be planted on its own or combined with other species such as Litsea, cashew, rubber, and eucalypts.

Techniques to plant cassava have been studied in several regions. With support from the Nippon fund of Japan, CIAT's Institute of Agro-chemistry and Soil carried out cassava research in Đong Rạng village in Hoa Binh province. The study concluded that on sloping land, cassava should be cultivated along the contour or in terraced fields, intercropping with rows of grass or species of beans, in order to limit soil erosion. Additionally, vegetable manure should be added to improve the land. Other studies indicated that cassava should be planted in combination with peanuts to limit soil erosion and improve soil fertility.

Use and value: In Vietnam, cassava has brought considerable income to many rural communities. In the past few years, a number of new cassava genera from Thailand have been popularly cultivated. These genera often have higher starch content, which can reach about 20-40% of bulb weight.

Cassava is the most important food source after rice, because it is highly adaptive and can be easily cultivated. Cassava crops can be highly productive; under suitable conditions (i.e., good soil and climate), productivity can reach 30-40 ton of fresh bulb/ha. Cassava is used as food for human and animals, as a component of cake, alcohol, sodium glutamate and many other products. Cassava leaves can be fed to fish and silkworms. In addition, the leaves are also used for fuel.

In its fresh form, cassava contains a poisonous substance called glucozit. This substance is found mostly in the bark and the two heads of the bulb, especially in young bulbs. When soaked in water and especially in gastric juices, the substance decomposes into acid xyanhydric (HCN) which is very poisonous for humans and animals. Therefore, it is necessary to avoid fresh processing of cassava to reduce poisoning incidents.

3.2 Description of research area

Research location

Three villages were involved in the research: H'Lim and Chup villages belonging to the Lo Pang commune; and Groi belonging to the Kon Thụp commune. Both communes are in the Mang Yang District, Gia Lai province of the Central Highlands of Vietnam.

These villages are inhabited by the Banar ethnic minority, who have experimented with innovative mono-cultivation of cassava using the Litsea-Cassava agroforestry model.

Natural conditions

- Climate: Average temperature of the warmest month of year is 23.8^0C, usually in May. The coldest month is January with an average temperature not less than 18.6^0C, providing an annual range of 5.2^0C. The rainy season is from May to October, with large amounts of rain. The mean annual rainfall is 2200 mm. The severe dry season lasts for four months from December to March, causing a water shortage. Winds are most frequently from the east to northeast in the rainy season and from the west to southwest in the dry season. This reduces humidity and achromatizes the soil color during the dry season, influencing the growth of cultivated crops. Annual average air humidity is 82%.
- Topography and soil: Average elevation above sea level varies from 600 to 750 m; the average slope is 7^0. The terrain has a slightly regular relief. Steep slopes from 5 to 15^0 can be observed in the high mountains. The main soils types include: reddish brown developed on basalt bedrock; exhausted grey soils developed on granite bedrock and distributed commonly on hillsides and very poor forest; and reddish yellow developed on granite, distributed in the high mountains. The pH varies from 5.5 to 6.7.
- Hydrology: The Đak Hla stream and the Yun river system provide essential water irrigation for crops. However, there is still not enough water for irrigation during the dry season.

Socioeconomic conditions

The main residents of the study area are from the Banar ethnic minority. There were 1379 households living in the two communes. Households cultivate upper paddy-fields. Through conventional and improved processes, a variety of crops (e.g., wet-rice, pepper, rubber) and animals (particularly cows) can be found in the area. The upper paddy-fields comprise around 510 ha and are planted with a cassava crop. Since the paddy-fields could not be expanded and there was a risk of the soils becoming exhausted, the local farmers have adopted Litsea to build their agroforestry model. The components in this model comprise Litsea and cassava. The model has a total area of 166 ha, of which 68 ha are in the Kon Thup commune and 98 ha in the Lo Pang commune. The model has replaced mono-cultivation with cassava due to the economic profit obtained from Litsea and its effect on sustainable land use.

In the study site, there are many poor and starving households, with 60.2% and 45.3% for Lo Pang and Kon Thụp, respectively, because the main source of sustenance is rice (wet rice and upper rice). Commercial plants, such as pepper and rubber have not been cultivated much in these areas. Moreover, even though the Litsea-Cassava agroforestry model has brought considerable and frequent income to households, the crop has an average area of only 1.2 ha per household. Therefore, the agroforestry model should be expanded to other mono-cultivated cassava farms. Likewise, the farmers need help to connect with the market for Litsea to earn more income.

The study sites have a well-developed infrastructure, including an electricity network, a primary school, and a medical station. The road system is relatively convenient as a means of transport from the commune centers in the district. Although the inter-village roads are not sealed, they are very useful in transporting Litsea products to the market.

4 RESEARCH COMPONENTS, METHODS, & LOGIC

4.1 Research component

To achieve the research objectives, the following research components were undertaken:

i) Measurement of the growth of Litsea in the Litsea-Cassava agroforestry model and the development of a Litsea volume table.
ii) Construction of a model to estimate the average fresh biomass and dry biomass of Litsea.
iii) Estimation of stored carbon in an average Litsea tree.
iv) Prediction of biomass, stored carbon and CO_2 concentration in the Litsea-Cassava agroforestry model.
v) Analysis of the environmental-economic values of CO_2 concentration in Litsea in the Litsea-Cassava agroforestry.

4.2 Research methodology

4.2.1 Methodology

Biomass and stored carbon in woody trees have an organic relationship, while, at the same time, in agroforestry models, the capacity to store carbon in woody tree has an ecological relationship depending on factors including: the associated rate between woody trees and agricultural crops, woody tree density, associated time, business cycle, and the mode of regeneration e.g. from seeds or copy for shoots. Therefore, it is essential that the experimental method involves: sampling according to the objectives; conducting chemical laboratory tests to determine the stored carbon in the components of the tree; and then using multi-variables to estimate the biomass and stored carbon in the agroforestry models. This procedure forms the basis of predicting the CO_2 concentration in woody trees in the agroforestry model according to the age period, the cycle, and different combinations.

4.2.2 Method of sampling and data collection

Litsea sample plots: A total of 22 circular Haga plots, each with an area of 300 m^2 was established in different ratios based on the age of the stand (1-7 years). Density varied from 500 to 2000 tree/ha. There were three cycles, involving seed or coppicing from shoots. While cassava is used for land cover, its coverage ranges from 15 – 80% depending on the age and density of Litsea. Data collected in the sample plots included:

- Inventory of ecological factors: % vegetation cover, soil color, depth of soil layer, soil pH, humidity, % gravel, % exposed rock, elevation a.s.l., position, slope, and aspect.
- Forest inventory: diameter at breast height ($D_{1.3}$), tree height (H), and crown area (St).

Stem analysis to measure fresh biomass of an average tree and to obtain specimens for carbon analysis of Litsea

Analysis of an average tree in the forest stand to collect growth data, fresh biomass, and specimen samples to analyze carbon: In each sample plot, the quadratic stand diameter (Dg) was calculated. Sample trees, based on Dg, were selected for analysis. The sample trees were partitioned into five equal sections and the diameter of each section was measured to calculate tree volume. Tree components, such as stem, branches, bark, and leaves were weighed to determine fresh biomass. In each sample component, a set of precision scales was used to sample 100 g for analysis to estimate the dry biomass and carbon pool in each component. There were 88 samples used to determine the stored carbon content in Litsea.

Weighing to define the fresh biomass of the four componenets of Litsea: stem, branches, leaves, and bark

Sampling of the four componenets of Litsea to analyze carbon pools in the stem, branches, leaves, and bark

Interview of local famers to obtain information on productivity and the local price of crops in the agroforestry model: The information collected included: the cost of 1 ha of agroforestry at different combined ratios; the cycle; cassava productivity under the different cycles and combined ratios; Litsea price for the whole tree (stem, bark, branches, and leaves) according to diameter and age; cassava price and income following the cycles and combined ratios.

4.2.3 Methods of data analysis and model establishment

Litsea volume: Calculation of stem volume based on measurements from the five equal sections.

Dry biomass of average tree: Fresh sample were oven dried at 105^{o}C until completely dry to achieve constant weight, which defined dry biomass and allowed the estimation of % dry biomass compared to fresh biomass.

Analysis of carbon pools in individual components of the tree: Using an oxidizing method of organic matter by $K_2Cr_2O_7$ according to the Walkley–Black (1934) method , the carbon content was determined by a green (or blue) color comparison of Cr3+ created ($K_2Cr_2O_7$) at the spectral wavelength of 625 nm. The %C in dry biomass was defined later. Based on the % dry weight compared to the fresh weight, the stored C in each tree component for the average tree were calculated. The CO_2 concentration based on an average tree was transformed by the equation: $CO_2 = 3.67C$.

ANOVA was used to assess statistical differences among the amounts of carbon in each tree component.

Multivariable regression analysis yi = f(xj): Modeling of relationships between volume, biomass, stored carbon and absorbed CO_2 was carried out using inventory data from the average tree and stand age (A), Dg, Hg, N/ha, shoot density/ha, and the average number of shoots.

*Synthetic analysis of economic and environmental values of the agroforestry model: The e*conomic effect of the model was calculated using normal economic methods based on the income and expenditure associated with each tree species in the agroforestry model. The CO_2 value was defined based on the internationally common price and CO_2 prediction of an average tree and a 1 ha unit in the model.

5 RESULTS AND DISCUSSIONS

5.1 Average growth of Litsea in the *Litsea-Cassava* agroforestry model and the volume table for Litsea

From data analyzed on the average tree based on age (A), the average characteristics of the stand were defined, including: quadratic diameter (diameter of a tree of average basal area) (Dg) and mean tree height corresponding to Dg (Hg). Tree volume was calculated from the measurements taken from the five equal tree sections. The Schumacher model was selected to estimate the growth process of Litsea.

Table 5.1 Allometric relationships of Litsea in the *Litsea-Cassava* agroforestry model.

Allometric **model of average Litsea tree**	**R^2**	**P**	**No.**
log(Dg cm) = 3.0356 - 3.03621*A^-0.5	0.856	0.00	(5.1)
log(Hg m) = 3.88083 - 3.48973*A^-0.2	0.693	0.00	(5.2)
log(V m3) = 1638.28 - 1646*A^-0.001	0.735	0.00	(5.3)

log = Napier logarithm.

From the models above, the average characteristics of the growth of Litsea were estimated in the agroforestry model.

Table 5.2 Growth and increment of an average Litsea tree in the *Litsea-Cassava* agroforestry model.

A (year)	Dg (cm)	Δd (cm/year	Hg (m)	Δh (m/year)	V (m^3)	Δv (m^3/year)
1	1.0	1.0	1.5	1.5	0.000444	0.000444
2	2.4	1.2	2.3	1.2	0.001389	0.000694
3	3.6	1.2	2.9	1.0	0.002705	0.000902
4	4.6	1.1	3.4	0.9	0.004341	0.001085
5	5.4	1.1	3.9	0.8	0.006264	0.001253
6	6.0	1.0	4.2	0.7	0.008452	0.001409
7	6.6	0.9	4.6	0.7	0.010887	0.001555
8	7.1	0.9	4.8	0.6	0.013558	0.001695
9	7.6	0.8	5.1	0.6	0.016451	0.001828
10	8.0	0.8	5.4	0.5	0.019559	0.001956

Δd, Δh, Δv = average increment of d, h, v

For Litsea, the annual mean increment of Dg varied from 0.8 to 1.2 cm/year, with strong diameter growth at age 2-3 years. Annual height growth ranged from 0.5 to 1.5 m/year, with rapid height growth in the early period. Volume increased gradually from age 1 to10 years, which indicated that biomass was still increasing in Litsea at the age of 10 years and had not reached quantitative maturity with respect to volume. Due to a lack of cash, farmers, who cultivate Litsea for cash, usually sell their crop at a young age, normally at 6-8 years old. ***Therefore harvesting post-ten-year-old Litsea is recommended for famers to obtain a greater volume of wood and thus command a better income***.

The standing volume of Litsea was defined by its relationship with Dg and Hg, using individual tree stem for the modeling.

Volume model	**R^2**	**P**	**No. of model**
log(V, m3) = -8.51825 + 1.48519*log(Hg, m) + 0.852795*log(Dg cm)	0.976	0.00	(5.4)
log(V, m3) = -8.0519 + 1.77111*log(Dg, cm)	0.933	0.00	(5.5)

log = Napier logarithm.

The relationship between tree volume (V) using both Dg and Hg gave a higher R^2 value compared with just using Dg. Hence, volume should be estimated based on both D and H. However the simple regression model between V and Dg also resulted in a relatively high R^2 value ($R^2 = 0.933$). Therefore, V can be determined using just D, which is easier to measure if a very high level of accuracy is not required.

Table 5.3 Volume (m^3) table of Litsea species using $D_{1.3}$ and H.

$D_{1,3}$ (cm)	H (m)												
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
1.0	0.000200	0.000365	0.000559										
1.5		0.000516	0.000790	0.001101	0.001443								
2.0		0.000659	0.001010	0.001407	0.001845	0.002319							
2.5		0.000797	0.001222	0.001702	0.002231	0.002805	0.003421						
3.0			0.001427	0.001988	0.002607	0.003277	0.003996	0.004760					
3.5			0.001628	0.002268	0.002973	0.003738	0.004557	0.005429					
4.0			0.001824	0.002541	0.003331	0.004188	0.005107	0.006083					
4.5				0.002810	0.003683	0.004631	0.005647	0.006726	0.007866	0.009062			
5.0				0.003074	0.004030	0.005066	0.006178	0.007359	0.008605	0.009914			
5.5					0.004371	0.005495	0.006701	0.007982	0.009334	0.010753			
6.0					0.004707	0.005919	0.007217	0.008596	0.010053	0.011581	0.013179		
6.5						0.006337	0.007727	0.009204	0.010763	0.012399	0.014110		
7.0						0.006750	0.008231	0.009804	0.011465	0.013208	0.015030	0.016928	0.018897
7.5							0.008730	0.010398	0.012160	0.014009	0.015941	0.017954	0.020042
8.0							0.009223	0.010987	0.012848	0.014801	0.016843	0.018969	0.021176
8.5							0.009713	0.011570	0.013529	0.015587	0.017737	0.019976	0.022300
9.0							0.010198	0.012148	0.014205	0.016365	0.018623	0.020974	0.023414
9.5								0.012721	0.014876	0.017138	0.019502	0.021963	0.024519
10.0								0.013290	0.015541	0.017904	0.020374	0.022945	0.025615
10.5								0.013854	0.016201	0.018664	0.021239	0.023920	0.026703

5.2 Ratios of carbon stored in the biomass of Litsea

The %C in fresh biomass and in each component of the tree, as well as in the whole tree were calculated based on %C content in the dry biomass of the four components of the stem, branches, bark, and leaves. Based on these results, the capacity to store carbon in individual parts of the tree, in the whole tree, and in fresh and dry biomass was compared.

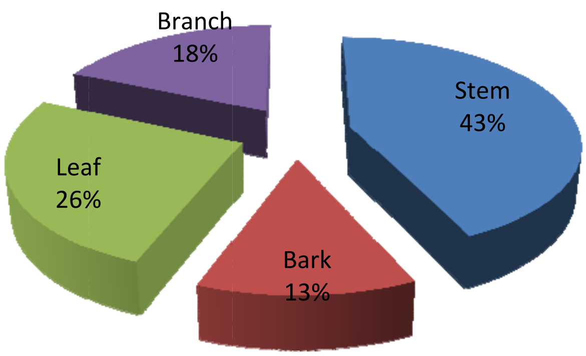

Figure 5.1 %C in the components of a Litsea tree compared to total C.

The highest stored carbon was observed in the stem, accounting for 43%, followed by the leaves with 26%, while those of branch and bark were 18 and 13%, respectively. The results of ANOVA indicated that there was a significant difference (P<0.05) among the ratios of C stored in the four components of the tree.

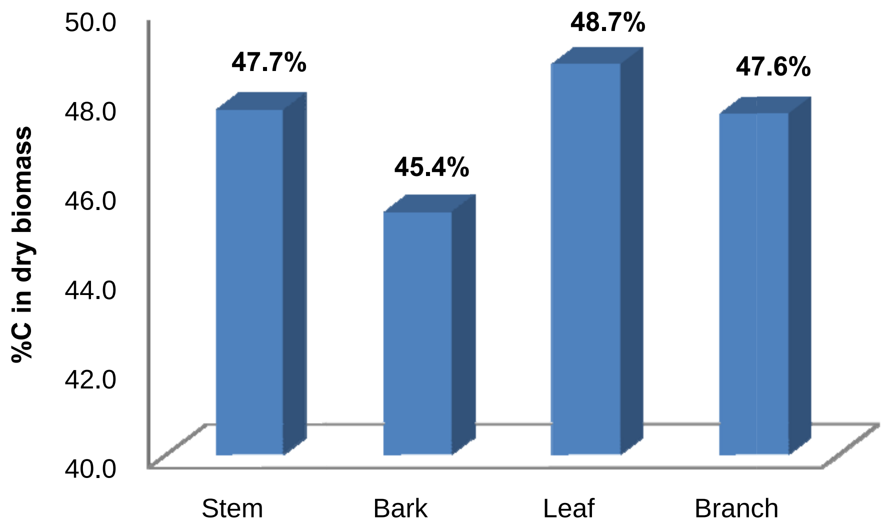

Figure 5.2 %C in the dry biomass of the tree components of Litsea.

Within the four tree components of Litsea, the highest amount of stored carbon in the dry biomass was in the leaves with 48.7%, while stem and branches had about the same amount with 47.6 and 47.7%, respectively. The lowest amount was observed in the bark with 45.4% of stored carbon. ***The %C in the dry biomass compared to a complete average tree was 47.4%.***

ANOVA: The %C in the dry biomass was compared based on two factors: the four components of the tree and the age from 1 to 7 years. The results show that at different ages the carbon rate was not statistically significantly different (P = 0.35 > 0.05), whereas the different components exhibited a significant difference ($P < 0.05$). ***This implies that estimates of stored carbon based on dry biomass should not consider age, but attention should be given to the different components. In other words, it is necessary to define the dry biomass according to the individual components of stem, bark, branches, and leaves. Carbon stored in individual components can be calculated based on %C of these components, and stored C for the whole tree is then the sum of all the components.***

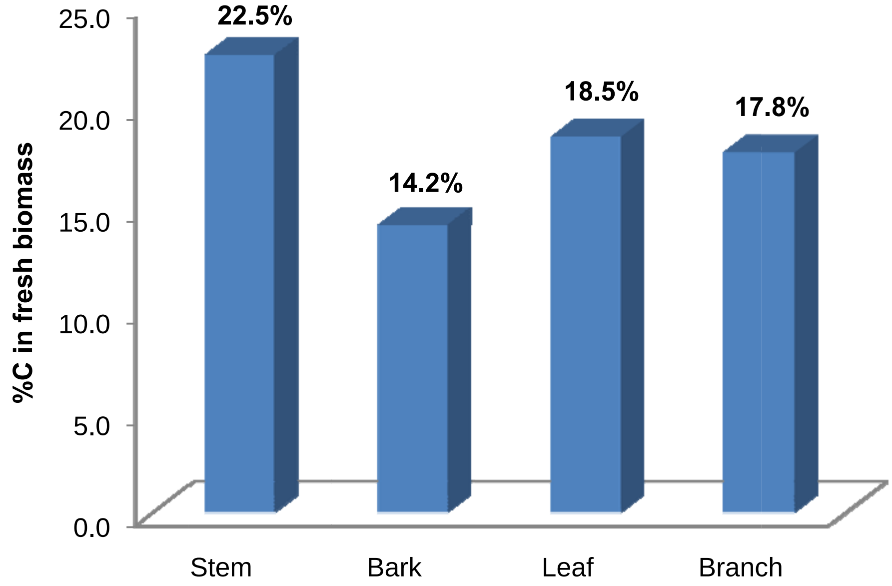

Figure 5.3 %C in the fresh biomass of the tree components.

Among the four components of the tree, the stem contained the highest carbon in the fresh biomass with 22.5%, followed by the leaves with 18.5%, branches with 17.8%, and the lowest was in the bark with 14.2%. ***The %C in the fresh biomass compared to a complete average tree was 18.2%.***

ANOVA: The %C in the dry biomass was compared according to two factors: the four components of the tree and the age from 1 to 7 years. The results showed that at different ages the carbon rate was statistically significantly different ($P < 0.05$). ***This implies that in the estimation of stored carbon based on fresh biomass, age should be considered and attention should be given also to the different components of stem, branches, leaves, and bark. Carbon stored in individual components can be calculated based on the %C in these components, and stored C for the whole tree is the sum of all the components.***

5.3 Estimates of fresh and dry biomass of Litsea

The estimation of the amount of stored carbon in a tree should be based on the biomass of the components of the whole tree. Otherwise, it is a time-consuming and costly process, if a direct measurement of biomass is undertaken by cutting the tree down, weighing it and using an oven for drying samples. Using data collected from a typical tree, the fresh biomass of the tree components was determined, while the dry biomass of the components was estimated using sample analysis. The fresh and dry biomass were indirectly estimated through model construction.

Dry and fresh biomass percentages in Litsea

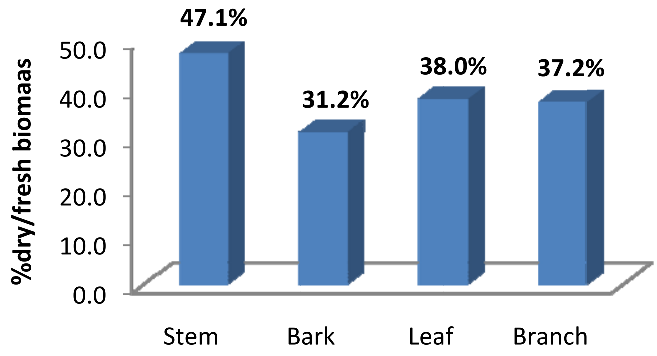

Figure 5.4 % dry biomass/fresh in components of the tree.

The results of ANOVA analysis of % dry biomass/fresh biomass indicated that there was a statistically significant difference ($P<0.05$) at different ages and for the different components of the tree.

The highest % of dry biomass/fresh biomass was for the stem with 47.1%, followed by leaves with 38.0%, branches with 37.2% and the lowest was for the bark with 31.2%. The average % dry biomass/fresh biomass was 38.4%.

Estimation of the dry biomass from the fresh biomass should be based on tree age and tree components such as the stem, branches, leaves, and bark.

Estimate of fresh biomass using directly inventoried factors of the tree

The models used to estimate the fresh biomass of the tree components and for the whole tree were based on Dg, which is easier and cheaper to measure.

Table 5.4 Models used to estimate the fresh biomass of the components and for an individual Litsea tree.

Equations to estimate of fresh biomass for an individual tree based on Dg	R^2	P	No. of models
log(stem fresh biomass kg) = -1.34349 + 1.67159*log(Dg cm)	0,931	0.00	(5.6)
log(bark fresh biomass kg) = -2.30494 + 1.80529*log(Dg cm)	0.936	0.00	(5.7)
log(leaf fresh biomass kg) = -0.944707 + 1.1055*log(Dg cm)	0.725	0.00	(5.8)
log(branch fresh biomasskg) = -1.69105 + 1.46917*log(Dg cm)	0.853	0.00	(5.9)
log(tree fresh biomass kg) = -0.0600462 + 1.47477*log(Dg cm)	**0.916**	**0.00**	**(5.10)**

log = Napier logarithm

From the models above, the fresh biomass of the tree and the tree components can be estimated using tree diameter. From the model Dg = f(A), Dg was defined with respect to age, and by replacing Dg in the model shown in Table 5.5, the fresh biomass of the components and the tree can be calculated.

Table 5.5 Fresh biomass of an average Litsea tree.

A (year)	Dg (cm)	Fresh biomass of tree components (kg)					Fresh biomass of tree (kg)
		Stem	Bark	Leaf	Branch	Total	
1	1.0	0.3	0.1	0.4	0.2	0.9	**0.9**
2	2.4	1.2	0.5	1.0	0.7	3.4	**3.5**
3	3.6	2.2	1.0	1.6	1.2	6.1	**6.2**
4	4.6	3.3	1.5	2.1	1.7	8.6	**8.8**
5	5.4	4.3	2.1	2.5	2.2	11.0	**11.2**
6	6.0	5.3	2.6	2.8	2.6	13.2	**13.3**
7	6.6	6.1	3.0	3.1	3.0	15.2	**15.2**
8	7.1	6.9	3.4	3.4	3.3	17.1	**17.0**
9	7.6	7.7	3.9	3.6	3.6	18.8	**18.6**
10	8.0	8.4	4.2	3.9	3.9	20.4	**20.1**

The results showed that the estimate of fresh biomass using the four components, and then summing them could provide an approximate estimate of the fresh biomass for the whole tree based on Dg***. Therefore, in order to estimate the overall fresh biomass for an average tree, it is only necessary to use Dg to obtain the estimate.***

Estimate of dry biomass using directly inventoried factors of the tree

The models used to estimate the dry biomass of the tree components and for the whole tree were based on Dg, which is easier and cheaper to measure.

Table 5.6 Equations of dry biomass estimate of average tree of Litsea

Equations to estimate dry biomass based on Dg	R^2	P	No. of models
log(stem dry biomass kg) = -2.31337 + 1.81765*log(Dg cm)	0.935	0.00	(5.11)
log(bark dry biomass kg) = -3.68511 + 1.94248*log(Dg cm)	0.929	0.00	(5.12)
log(leaf dry biomass kg) = -2.02567 + 1.19235*log(Dg cm)	0.759	0.00	(5.13)
log(branch dry biomass kg) = -2.85803 + 1.59805*log(Dg cm)	0.871	0.00	(5.14)
log(tree dry biomass kg) = -1.16425 + 1.60676*log(Dg cm)	**0.923**	**0.00**	**(5.15)**

log = Napier logarithm.

From the models above, the dry biomass of the tree and the tree components can be estimated using tree diameter. From the model Dg = f(A,) Dg was defined with respect to age, and by replacing Dg in the model shown in Table 5.6, the dry biomass of the components and the tree can be calculated.

Table 5.7 Dry biomass of an average Litsea tree.

A (year)	Dg (cm)	Dry biomass of tree components (kg)					Dry biomass of tree (kg)
		Stem	Bark	Leaf	Branch	Total	
1	1.0	0.1	0.0	0.1	0.1	0.3	**0.3**
2	2.4	0.5	0.1	0.4	0.2	1.3	**1.3**
3	3.6	1.0	0.3	0.6	0.4	2.4	**2.5**
4	4.6	1.6	0.5	0.8	0.6	3.5	**3.6**
5	5.4	2.1	0.7	1.0	0.8	4.6	**4.6**
6	6.0	2.6	0.8	1.1	1.0	5.5	**5.6**
7	6.6	3.1	1.0	1.3	1.2	6.5	**6.5**
8	7.1	3.5	1.1	1.4	1.3	7.3	**7.3**
9	7.6	3.9	1.3	1.5	1.5	8.1	**8.1**
10	8.0	4.3	1.4	1.6	1.6	8.9	**8.8**

The results show that the estimate of dry biomass using the four components, and then summing them could provide an approximate estimate of the dry biomass for the whole tree using Dg. ***Therefore, in order to estimate the overall dry biomass for an average tree, it is only necessary to use Dg to obtain the estimate.***

In summary, the Dg can be used to estimate the dry and fresh biomass of an average Litsea tree in the model, and also of the individual components. The %C in dry biomass/fresh is used to determine the stored carbon in each tree component and in the tree with respect to tree age and the size of the average tree.

5.4 Direct estimate of stored carbon in individual components and the whole Litsea tree

The results above can be used to estimate the stored carbon in an average Litsea tree. However, the estimates are obtained through intermediate equations. In addition, the calculations have to be done for the individual components, which is time consuming. Therefore, a direct estimation of carbon through Dg is preferable, which uses analyzed data of carbon from samples of the components.

Table 5.8 Estimates of carbon sequestration in tree components of Litsea.

Equations of carbon estimation based on Dg	R^2	P	No. of models
log(C of stem kg) = -3.05514 + 1.8237*log(Dg cm)	0.963	0.00	(5.16)
log(C of bark kg) = -4.45754 + 1.93655*log(Dg cm)	0.931	0.00	(5.17)
log(C of leaf kg) = -2.74975 + 1.19657*log(Dg cm)	0.764	0.00	(5.18)
log(C of branch kg) = -3.59605 + 1.59554*log(Dg cm)	0.870	0.00	(5.19)
log(C of the whole tree kg) = -1.90151 + 1.60612*log(Dg cm)	0.922	**0.00**	**(5.20)**

log = Napier logarithm

From the models above, the stored carbon in an average tree and in the tree components can be estimated using tree diameter. From the model Dg = f(A,), Dg can be defined with respect to age, replacing Dg in the model shown in Table 5.9, the carbon in the components and for the total tree can be calculated. From there, CO_2 concentration also can be predicted.

Table 5.9 Amount of C/CO_2 sequestration in tree components and an average Litsea tree.

A (year)	Dg (cm)	C (kg) in tree components					C in the whole tree (kg)	CO_2 in the whole tree (kg)
		Stem	bark	Leaf	Branch	Total		
1	1.0	0.0	0.0	0.1	0.0	0.1	**0.1**	0.55
2	2.4	0.2	0.1	0.2	0.1	0.6	**0.6**	2.28
3	3.6	0.5	0.1	0.3	0.2	1.1	**1.2**	4.30
4	4.6	0.7	0.2	0.4	0.3	1.7	**1.7**	6.27
5	5.4	1.0	0.3	0.5	0.4	2.2	**2.2**	8.11
6	6.0	1.2	0.4	0.5	0.5	2.7	**2.7**	9.81
7	6.6	1.5	0.4	0.6	0.6	3.1	**3.1**	11.37
8	7.1	1.7	0.5	0.7	0.6	3.5	**3.5**	12.81
9	7.6	1.9	0.6	0.7	0.7	3.9	**3.9**	14.14
10	8.0	2.1	0.6	0.8	0.8	4.2	**4.2**	15.37

The results indicate that using Dg, the sum of the estimates of carbon for the four components, approximated the carbon estimate for the whole tree. ***Therefore, in order to estimate the total C/CO_2 concentration for an average tree, it is only necessary to use Dg to obtain the estimate.***

5.5 Prediction of biomass, stored carbon and concentrated CO_2 in the Litsea-Cassava agroforestry model

Estimate of CO_2 sequestration/ha by Litsea in the model

From the measurements and weights of the fresh biomass, dry biomass and carbon for an average tree, in combination with tree density data for Litsea, the three parameters were determined on a per-hectare basis for the model. Multivariable regression analysis was employed to detect the factors affecting the biomass and the stored carbon in the models involving different combinations of Litsea and cassava. The processes performed were:

- Normal test of independent and responsive variables.
- Test of relationships among the variables to select the variables that affect biomass and stored carbon in the model.
- Selection of optimal models to represent the per-hectare biomass and stored carbon of Litsea in the agroforestry model. The method to select the optimal models was based on determination of the coefficient R^2 at $P<0.05$. The effect was checked by parameters of the exploratory variables, which were tested by Student's standard t at $P<0.05$.

Table 5.10 indicates that ***the biomass and carbon stored in Litsea under the agroforestry model depended on several variables: a) number of shoots/stump (equal to 1 in cycle 1 and ≥ 1 in cycles 2 and 3; b) tree density/ha of Litsea in the model; and c) quadratic stand diameter of Litsea Dg.***

Table 5.10 Predictions of fresh/dry biomass and stored carbon in Litsea in the Litsea-Cassava model

Carbon estimate according to Dg	R^2	P	No. of the model
log(fresh biomass/ha, kg) = 4.2502 + 1.98843*No. of shoots/stump - 0.367147*No. of shoots/stump/^2 + 0.000939525*N (tree/ha) + 0.443267*Dg (cm)	0.909	0.00	(5.21)
log(dry biomass/ha, kg) = 2.94757 + 2.37022* No. of shoots/stump - 0.471556*shoots/stump^2 + 0.000934184*N(tree/ha) + 0.468955*Dg (cm)	0.906	0.00	(5.22)
log(C/ha, kg) = 2.12434 + 2.48948* No. of shoots/stump - 0.500269* No. of shoots/stump^2 + 0.000922418*N (tree/ha) + 0.469249*Dg (cm)	0.905	0.00	(5.23)

The parameters of independent variables of the models above were tested using Student's t test. All parameters were tested at P < 0.00.

log = Napier logarithm.

The results above show that biomass and stored carbon per hectare in Litsea under the agroforestry model depended on three different factors: a) the number of shoots/stump: the more shoots, the higher the biomass and C that can be obtained. However, too many shoots can cause a decrease in biomass and stored carbon; b) tree density per hectare: the layout of the agroforestry model varies depending on each famer's requirements; the greater the stocking of Litsea, the higher the biomass and C stored; c) The average diameter Dg: the size of the Litsea trees in the model is positively linked with biomass and carbon stored . ***The three models above were employed to estimate fresh and dry biomass, and stored carbon per hectare in the Litsea-Cassava model.***

The results indicated that the CO_2 sequestration in Litsea in the agroforestry model can be predicted by the following three methods:

- *Based on %C stored compared to the biomass of each tree component of Litsea:* sampling was used to define the fresh and dry biomass of the four tree components (stem, bark, leaves, and branches) and the density of shoots/ha. Stored carbon in the individual components of the tree may be calculated based on dry biomass, while average carbon stored in the whole tree is the sum of these components. In the end, stored carbon per hectare is calculated by multiplying by the shoot density/ha, and CO_2 is estimated using the equation $CO_2 = 3.67C$ to get the absorbed CO_2 /ha in the model. Although this method gave the best result, it was at high cost and it was also time consuming to determine the fresh/dry biomass of an average tree.

- *Based on the model of C/individual tree = f(Dg)*: sampling was used to define Dg and shoot density/ha, using the model to calculate stored carbon in an average tree, and then multiplying by the shoot density/ha to get the absorbed CO_2/ha from the model. This method had a relative error of 3.2% when used to define CO_2/ha.
- *Based on the model C/ha = f(No. shoots/stump, N/ha, Dg):* sampling was used to determine the average number of shoots/stump, N/ha and Dg and then using the model to estimate the stored carbon /ha. The relative error of this method was 2.7% for estimating CO_2/ha.

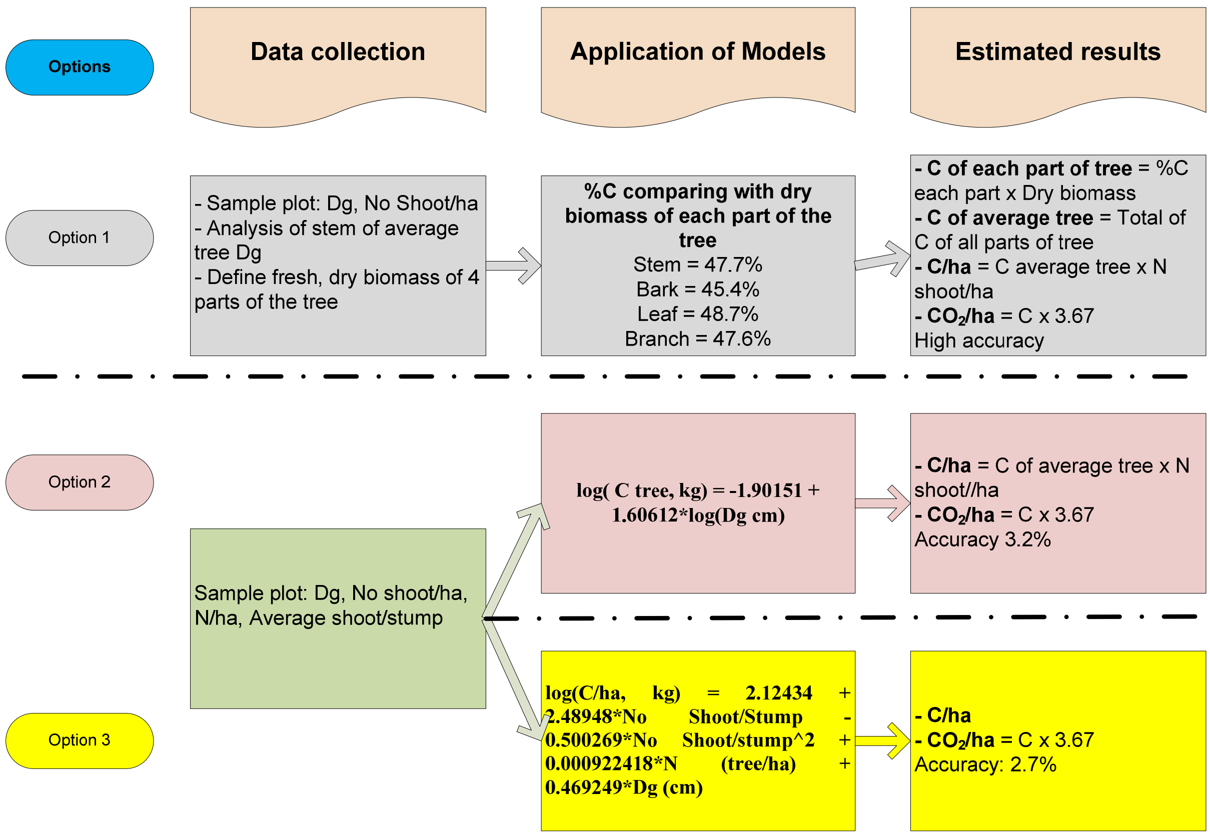

Figure 5.5 Application of the models to estimate CO2 sequestration in Litsea in the Litsea-Cassava agroforestry model.

Optimizing biomass and absorbed CO_2 of Litsea in the Litsea-Cassava agroforestry model

In practice, the number of shoots kept on each stump was different in the second and third cycles of Litsea,. This may affect productivity, biomass and accumulated carbon in the model. Based on the models in Table 5.10, the optimal number of shoots per stump should be left in the second and third cycles to gain the greatest biomass and carbon storage.

The specific derivative of the three equations in Table 5.10 for the variables shoots/stump, N/ha and Dg was considered constant, so the required number of shoots/stump to achieve the greatest dry/fresh biomass and stored carbon was calculated.

The general model is:

log(biomass, C) = a + b_1. No. of shoots – b_2. * No. of shoots ^{2} + b_3. *N + b4. *Dg

The specific derivative for the number of shoots was equated to zero (Equation 5.24):

$$\frac{d(\log(biomass,C)}{d(numbet\ of\ shoots)} = b1 - 2b2\ number\ of\ shoots = 0 \qquad (5.24)$$

The optimal number of shoots to obtain the highest amount of biomass and stored carbon in the agroforestry model was calculated using Equation 5.25:

$$Optimal\ number\ of\ shoots/stump = \frac{b1}{2b2} \qquad (5.25)$$

The result indicated that the average number of shoots was 2.5-2.7/stump to produce the highest biomass and stored carbon in the model. In practice, regardless of the value of concentrated CO_2 in Litsea, if a higher biomass were obtained, the income was higher due to income not only coming from the stem biomass, but also from leaves, bark, and branches. ***Therefore, within cycle of 2 and 3 of this model, maintaining 2-3 shoots/stump will have the greatest effect not only on productivity, but also on absorbed CO_2.***

From the three models above (in Table 5.10), the optimal dry/fresh biomass and concentrated CO_2 were achieved with an optimal number of 2 shoots/stump and a mean density of 1300 stumps/ha. The results also show an optimal capacity of CO_2 absorption in the range from 3 to 84 ton/ha depending on the ages in the model.

Table 5.11 Per hectare predictions of fresh/dry biomass and the optimal CO_2 absorbed by Litsea in the Litsea-Cassava model.

A (year)	No. optimal shoot /stump	N/ha average	Dg (cm)	Fresh biomass /ha (ton)	Dry biomass/ha (ton)	Carbon/ha stored by Litsea (ton)	CO_2/ha absorbed by Litsea(ton)
1	2	1300	1.0	5	2	0.9	3.2
2	2	1300	2.4	9	3	1.7	6.3
3	2	1300	3.6	14	6	3.0	10.9
4	2	1300	4.6	22	9	4.6	17.0
5	2	1300	5.4	31	14	6.7	24.7
6	2	1300	6.0	42	19	9.2	33.8
7	2	1300	6.6	55	25	12.1	44.4
8	2	1300	7.1	68	31	15.4	56.4
9	2	1300	7.6	84	39	19.0	69.7
10	2	1300	8.0	100	47	22.9	84.2

5.6 Prediction of economic and environmental values in the agroforestry model

In order to estimate the economic-environmental values of the model, it is necessary to calculate:

- Economic values in the model, including the economic values for both Litsea and cassava.
- In this case, the environmental value under consideration was the CO_2 concentration in Litsea.

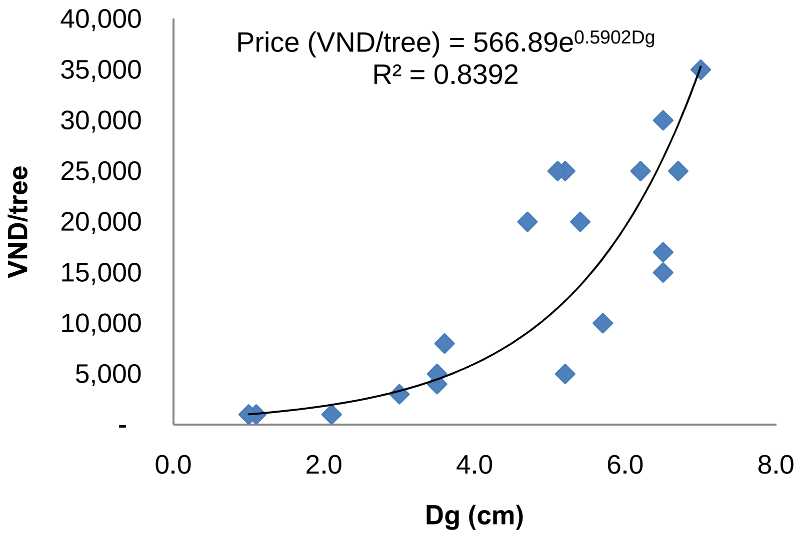

Figure 5.6 Value of Litsea based on Dg.

Litsea was valued based on the local price of Litsea (2007 – 2008). This was applied to the components of the whole tree (stem, branches, leaves and bark), based on the diameter. An exponential model was used to estimate the price of Litsea based on Dg. Litsea is sold at varying sizes, therefore, its price fluctuates, from VDN 8000 /tree for Dg = 4cm to 35 000/tree for Dg = 7cm.

The productivity of cassava in the Litsea-Cassava agroforestry model varied over time (A) and with the density of Litsea (N/ha). Based on the productivity/ha of cassava in the agroforestry model according to the ages and tree densities in sample plots, regression models were used to express the relationship between cassava productivity and A and N/ha of Litsea (Equation 5.26):

$$\log(\text{cassava productivity/ha, ton}) = 11.3699 - 0.298601 * A(\text{year}) - 1.28345 * \log(N/ha) \quad (5.26)$$

$R^2 = 0.481$ at $P<0.05$, parameters were tested by t at $P <0.05$
log = Napier logarithm.

The above model indicates that the higher the Litsea density and the longer the time, the lower the cassava productivity. From this model, the productivity of cassava in different models (with different rates and times in the agroforestry model) can be predicted, which is then used to calculate the economic value of cassava in the model, using an average price of VND 600 000/ton.

Predictions of the economic and environmental value of the agroforestry model may be estimated based on: the modeled value of Litsea, based on Dg; the modeled cassava productivity, using A and N/ha; the local price of cassava; and the carbon equation, using shoots/stump, N/ha and Dg.

Table 5.12 shows the economic and environmental predictions in the model for the number of optimal shoots/stump = 2 and an average Litsea density of 1300 trees/ha.

Table 5.12: Predicted economic and environmental values of the Litsea-Cassava agroforestry model according to business cycle.

A (year) Business cycle	Number of Litsea shoots/stump	N/ha	Dg (cm)	Income of Litsea (VND/tree)	Litsea income/ha (million VND)	Productivity of cassava (ton/ha)	Accumulated income of cassava/ha (million VND) (VND 600 000/ton)	Total income/ha of Litsea and cassava (million VND)	CO_2/ha concentrated by Litsea (ton)	Income from CO2/ha (million) (USD 20/ton)	% income of CO_2 compared to total income of Litsea + cassava
2	2	1300	2.4	2,381	6.2	4.8	2.9	9.1	6.3	2.3	24.8%
3	2	1300	3.6	4,762	12.4	3.6	5.0	17.4	10.9	3.9	22.5%
4	2	1300	4.6	8,366	21.8	2.6	6.6	28.4	17.0	6.1	21.6%
5	2	1300	5.4	13,358	34.7	2.0	7.8	42.5	24.7	8.9	20.9%
6	2	1300	6.0	19,864	51.6	1.5	8.7	60.3	33.8	12.2	20.2%
7	2	1300	6.6	27,978	72.7	1.1	9.3	82.1	44.4	16.0	19.5%
8	2	1300	7.1	37,766	98.2	0.8	9.8	108.0	56.4	20.3	18.8%
9	2	1300	7.6	49,267	128.1	0.6	10.1	138.2	69.7	25.1	18.1%
10	2	1300	8.0	62,507	162.5	0.4	10.4	172.9	84.2	30.3	17.5%

1 ton of fresh cassava = VND 600 000; 1 ton of CO_2 = USD 20 x VND 18 000 = VND 360 000.

For a business cycle of five years, the total income from Litsea and cassava is VND 42.5 million/ha, while the CO_2 concentration is 24.7 ton/ha equal to USD 8.9 million/ha, which is 21% of the total income of products in the model.

If the business cycle varies from 5-10 years, the CO_2 absorbed in the model will vary from 24.7 to 84.2 ton/ha, equating to USD 8.9 to 30.3 million/ha, representing 18-21% of the total products from Litsea and cassava. Therefore, if there were a policy to encourage the development of agroforestry based on payment for the amount of CO_2concentrated, farmers would increase their income by about 20% based on the economic valuation in the model.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the research results, the conclusions are:

i) In order to obtain effective productivity, Litsea should be harvested after ten years. At present, farmers are harvesting Litsea at between 4-6 years. It is not advisable to harvest Litsea within this period because this is when strong growth occurs.

ii) The stored carbon and CO_2 sequestration in the Litsea-Cassava agroforestry model can be estimated in three ways:

- Based on the rate (%) of stored carbon compared to the dry biomass of the four components of tree: stem (47.7%), bark (45.4%), leaves (48.7%) and branches (47.6%), with carbon per hectare calculated based on tree density. Although this method gave the highest accuracy, it was, however, costly.
- Based on a model that estimates the carbon stored in the mean tree: C/tree = f(Dg), with carbon per hectare calculated based on tree density. This method had a relative error of 3.2%.
- Based on a model that estimated the carbon per hectare: C/ha = f(No of shoots/stump, N/ha, Dg). This method gave a relative error of 2.7%.

iii) The Litsea-Cassava agroforestry model in the second and the third periods should leave 2 to 3 Litsea shoots per stump. This will result in the greatest production of biomass and CO_2 concentration, with the possibility of optimal CO_2 absorption from 3 to 84 tons, increasing with age.

iv) The cycle of Litsea business varied over the 5-10 year period, while absorbed CO_2 in the agroforestry model varied from 25 to 84 tons per hectare. Profit from the model ranged from VND 9 to 30 million per hectare, representing 20% of the total product value of Litsea and cassava.

6.2 Recommendations

i) The research only predicted the amount of CO_2 in Litsea for the aboveground components. Since Litsea is cultivated for shoots over the period of two and three cycles, carbon is also stored underground in the roots and soil. Thus, a further study should be conducted to determine the carbon stored underground.

i) A policy is necessary, which encourages developing agroforestry models based on a fee for the environmental service provided by CO_2 absorption of forest trees. In the Litsea–Cassava agroforestry model, farmers' income would increase by about 20%, if they were paid for the environmental service based on the economic model.

References

1. Alves, D. S., J. V. Soares, et al. 1997. Biomass of primary and secondary vegetation in Rondonia, Western Brazilian Amazon. Global Change Biology 3:451-462.
2. Bao Huy, Pham Tuan Anh 2008. Estimating CO_2 sequestration in natural broad-leaved evergreen forests in the Central Highlands of Vietnam. Asia-Pacific Agroforestry Newsletter – APANews, FAO, SEANAFE; No.32, May 2008, ISSN 0859-9742.
3. Bao Huy 2009. Methodology for defining Carbon in natual forests to estimate CO_2 emission from deforestation and degradation in Vietnam. Magazine of Agriculture & Rural Development, No 1/2009. Hanoi; pp. 85 – 91.
4. Birdsey, A. 1996. Carbon storage for major forest and regions in the conterminous United States. In Forest and Global Change, volume 2: Forest managerment opportunities for mitigating carbon emissions, eds. R.N. Sampson and D. Hair, 1-26 and 261-379. Washington, DC: American Forests.
5. Brown, S. 2002. Measuring carbon in forests: current status and future challenges. Environmental Pollution 116: 363–372.
6. Cardinoza, M. 2005. Revising traditional NRM regulations (Tara Bandu) as a community-based approach of protecting carbon stocks and securing livelihoods. Carbon Forestry, Center for International Forestry Research, CIFOR.
7. Corbera, E. 2005. Bringing development into Carbon Forestry Markets: Challenges and outcomes of small – scale carbon forestry activities in Mexico. Carbon Forestry: Who will benefit. Proceedings of Workshop on Carbon Sequestration and Sustainable Livelihoods. Center for International Forestry Research, CIFOR.
8. Do Tat Loi (1967): Medicine plants in Vietnam. Pub. Education, Hanoi.
9. Erica, A. H. Smithwick et al. 2002. Potential upper bounds of carbon stores in forests of the Pacific Northwest, Ecological Society of America.
10. FCCC/SBSTA/2004/INF.7, 2004: Framework convention on climate change: Estimation of emissions and removals in land-use change and forestry and issues relating to projections. Note by the secretariat. http://www.unfccc.int. com (www.greenhouse.gov.au)
11. Gann, S.B. 2003. A Methodology for Inventorying Stored Carbon in an Urban Forest, Falls Church, Virginia.
12. Haswel, W. T 2000. Techniques for estimating forest carbon. Journal of Forestry 98(9): Focus, 1-3.
13. Hairiah, K., SM Sitompul, Meine van Noodoijk and Cheryl Palm 2001. Carbon stocks of tropical land use systems as part of the global C balance. Effects of forest conversion and options for clean development activities. International Centre for Research in Agroforestry, ICRAF.

14. Hairiah, K., SM Sitompul, Meine van Noodoijk and Cheryl Palm 2001. Method for sampling carbon stocks above and below ground. International Centre for Research in Agroforestry, ICRAF.

15. Hooverc et al. 2000. How to estimate carbon sequestration on small forest tracts. Journal of Forestry 98(9):13-19.

16. ICRAF 2006. Rapid Carbon Stock Appraisal (RaCSA)

17. James, E. Smith; Linda, S. Heath, and Peter, B. Woodbury 2004. How to estimate forest carbon for large areas from inventory data. Journal of Forestry. July/August: 25-31.

18. Kanninen, M., Murdiyarso, D. 2007. The implications of deforestation research for policies to promote REDD. CIFOR

19. Lewis, Oliver L. Phillipset et al., 2005. Tropical Forests and Atmospheric Carbon Dioxide: Current Knowledge & Potential Future Scenarios. Earth & Biosphere Institute, School of Geography, University of Leeds, Leeds. www.stabilisation2005.com

20. Le Van Minh 1996. Litsea plantation. Magazine of Forestry, No 4 – 5/1996. Ha Noi.

21. Murdiyarso, D. 2005. Sustaining local livelihood through carbon sequestration activities: A research for practical and strategic approaches. Proceedings of Workshop on Carbon Sequestration and Sustainable Livelihoods. CIFOR. pp:1-16

22. Ngo Dinh Que et al. 2006. Capacity of CO_2 sequestration of some main species for plantation in Vietnam. Magazine of Agriculture & Rural Development. No 7 /2006.

23. Nguyen Khac Hieu 2003. Proceedings of an international workshop on “Facilitating international carbon accounting in forests” held at CSIRO Forestry and Forest Products. Australian Academy of Technological Sciences and Engineering, Australia.

24. Pham Tuan Anh 2007. Forecasting CO_2 sequestration in natural forests in Tuy Duc District, Dak Nong Province, Vietnam. M.Sc. Thesis, Forestry University Vietnam

25. Pirard, R. 2005. Pulpwood plantations as carbon sinks in Indonesia: Methodological challenge and impact on livelihoods. Carbon Forestry, Center for International Forestry Research, CIFOR.

26. Rahman, M. 2004. Estimating Carbon Pool and Carbon Release due to Tropical Deforestation Using Highresolution Satellite Data. Dresden University of Technology, Germany.

27. Schimel, D.S. 1995. Terrestrial ecosystems and the carbon cycle. Global Change Biology 1: 77–91.

28. Smith, J. and Sara J. Scherr 2002. Forest Carbon and Local Livelihoods. Assessment of Opportunities and Policy Recommendations. CIFOR Occasional Paper No. 37.

29. Tran Van Con 2001. Define some species for production plantation in the North central highlands. Scientific Report. FSIV

30. Vo Dai Hai 2009. Research on capacity of carbon sequestration in Urophylla plantation in Vietnam. Magazine of Agriculture & Rural Development, No 1/2009, Ha Noi, pp. 102 – 106.

31. Vu Tan Phuong 2007. Define economic-environment value of some forest types in Vietnam. Research report. RCFEE, Hanoi.

32. Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci. 63:251-263.

APPENDICES

Appendix 1: Results from the analysis of 88 samples used to determine dry-weight biomass and carbon sequestration.

Sample code	Fresh-weight biomass sample (g)	Dry-weight biomass sample (g)		% weight of carbon in oven-dry sample		% weight of other components in dry sample
		Dry weight	% Dry Biomass	OD	%C	
A1T	100	50.9	50.9	0.37	48.1	51.9
A1V	100	29.6	29.6	0.36	47.5	52.5
A1L	100	39.1	39.1	0.37	48.8	51.2
A1C	100	38.4	38.4	0.36	47.7	52.3
A2T	100	51.9	51.9	0.36	46.8	53.2
A2V	100	33.9	33.9	0.34	45.2	54.8
A2L	100	35.9	35.9	0.38	50.1	49.9
A2C	100	35.4	35.4	0.35	46.7	53.3
A3T	100	47.7	47.7	0.35	46.6	53.4
A3V	100	30.2	30.2	0.33	43.9	56.1
A3L	100	37.3	37.3	0.38	49.9	50.1
A3C	100	39.0	39.0	0.36	47.5	52.5
A4T	100	47.6	47.6	0.36	47.0	53.0
A4V	100	34.6	34.6	0.35	45.7	54.3
A4L	100	37.5	37.5	0.35	45.8	54.2
A4C	100	37.8	37.8	0.37	48.6	51.4
A5T	100	42.2	42.2	0.37	49.2	50.8
A5V	100	26.5	26.5	0.35	46.2	53.8
A5L	100	33.3	33.3	0.37	48.8	51.2
A5C	100	31.3	31.3	0.36	47.6	52.4
A6T	100	48.6	48.6	0.36	47.6	52.4
A6V	100	28.6	28.6	0.34	44.8	55.2
A6L	100	39.1	39.1	0.38	49.7	50.3
A6C	100	37.3	37.3	0.36	47.4	52.6
A7T	100	49.8	49.8	0.36	47.9	52.1
A7V	100	31.7	31.7	0.34	45.1	54.9
A7L	100	38.8	38.8	0.36	47.5	52.5
A7C	100	38.4	38.4	0.34	45.4	54.6
A8T	100	45.2	45.2	0.37	48.4	51.6
A8V	100	29.2	29.2	0.35	45.8	54.2
A8L	100	38.3	38.3	0.38	50.2	49.8
A8C	100	35.9	35.9	0.37	48.8	51.2
A9T	100	46.0	46.0	0.36	47.2	52.8

Sample code	Fresh-weight biomass sample (g)	Dry-weight biomass sample (g)		% weight of carbon in oven-dry sample		% weight of other components in dry sample
		Dry weight	% Dry Biomass	OD	%C	
A9V	100	32.4	32.4	0.35	45.8	54.2
A9L	100	41.6	41.6	0.39	50.8	49.2
A9C	100	40.5	40.5	0.37	49.0	51.0
A10T	100	33.1	33.1	0.34	45.2	54.8
A10V	100	22.0	22.0	0.35	45.6	54.4
A10L	100	31.9	31.9	0.36	46.8	53.2
A10C	100	26.6	26.6	0.35	46.7	53.3
A11T	100	52.7	52.7	0.38	49.8	50.2
A11V	100	33.2	33.2	0.35	46.1	53.9
A11L	100	46.1	46.1	0.38	49.9	50.1
A11C	100	42.0	42.0	0.38	50.4	49.6
A12T	100	46.4	46.4	0.37	49.2	50.8
A12V	100	29.1	29.1	0.36	47.1	52.9
A12L	100	37.8	37.8	0.37	48.1	51.9
A12C	100	39.6	39.6	0.37	48.8	51.2
B1T	100	43.3	43.3	0.36	48.0	52.0
B1V	100	25.0	25.0	0.34	45.2	54.8
B1L	100	40.3	40.3	0.37	48.6	51.4
B1C	100	32.9	32.9	0.36	48.0	52.0
B2T	100	47.3	47.3	0.37	49.0	51.0
B2V	100	41.5	41.5	0.35	46.5	53.5
B2L	100	40.6	40.6	0.38	50.1	49.9
B2C	100	44.0	44.0	0.38	50.2	49.8
B3T	100	51.8	51.8	0.37	48.1	51.9
B3V	100	36.1	36.1	0.33	43.4	56.6
B3L	100	37.8	37.8	0.36	47.1	52.9
B3C	100	38.8	38.8	0.36	47.1	52.9
B4T	100	45.4	45.4	0.37	48.1	51.9
B4V	100	26.8	26.8	0.35	45.6	54.4
B4L	100	34.5	34.5	0.37	48.8	51.2
B4C	100	38.7	38.7	0.35	45.7	54.3
B5T	100	49.7	49.7	0.35	46.3	53.7
B5V	100	32.4	32.4	0.34	44.7	55.3
B5L	100	40.1	40.1	0.37	48.6	51.4
B5C	100	38.7	38.7	0.35	45.9	54.1
B6T	100	46.1	46.1	0.36	47.5	52.5

Sample code	Fresh-weight biomass sample (g)	Dry-weight biomass sample (g)		% weight of carbon in oven-dry sample		% weight of other components in dry sample
		Dry weight	% Dry Biomass	OD	%C	
B6V	100	26.3	26.3	0.35	46.1	53.9
B6L	100	36.1	36.1	0.37	48.6	51.4
B6C	100	35.2	35.2	0.35	46.3	53.7
B7T	100	41.3	41.3	0.37	48.1	51.9
B7V	100	26.7	26.7	0.35	45.8	54.2
B7L	100	35.6	35.6	0.37	49.2	50.8
B7C	100	37.5	37.5	0.35	46.6	53.4
B8T	100	46.4	46.4	0.39	50.7	49.3
B8V	100	33.3	33.3	0.36	48.0	52.0
B8L	100	41.4	41.4	0.37	49.2	50.8
B8C	100	39.3	39.3	0.35	46.7	53.3
B9T	100	40.0	40.0	0.37	48.8	51.2
B9V	100	28.5	28.5	0.36	47.7	52.3
B9L	100	38.7	38.7	0.39	50.7	49.3
B9C	100	32.6	32.6	0.38	49.4	50.6
B10T	100	48.6	48.6	0.37	49.2	50.8
B10V	100	35.6	35.6	0.35	46.7	53.3
B10L	100	40.6	40.6	0.35	45.8	54.2
B10C	100	40.4	40.4	0.36	47.9	52.1

B10 = the sample tree in sample plot B10; C = Branches; T = Stem; V= Bark; L = Leaves.

Appendix 2: Data of ecology, inventory, volume, and carbon biomass of mean sample trees of stands

Plot code	Model	Species	A year	seed shoot	Period	Annual crop	% area of cassava in the model	% vegetation cover	Soil sample	pH	% cobble	Elevation (m)	Position	Slope	Density tree/ha	Dentity shoot/ha
A1	Boi loi	Boi loi	4	1	1	1	0	10	1	6.4	20	714	2	5	1520	1620
A2	Boi loi	Boi loi	6	1	1	1	0	10	1	6.0	70	663	1	0	1633	1733
A3	Boi loi, san	Boi loi	5	1	1	2	40	5	1	6.3	30	654	1	0	1133	1267
A4	Boi loi, san	Boi loi	3	1	1	2	50	0	1	6.3	5	655	1	0	1367	1467
A5	Boi loi, san	Boi loi	1	2	2	2	60	0	2	6.6	0	676	1	0	1900	5033
A6	Boi loi, san	Boi loi	4	1	1	2	30	10	2	6.2	5	678	1	0	1800	2000
A7	Boi loi, san	Boi loi	3	1	1	2	50	10	2	6.2	10	664	1	0	1567	1933
A8	Boi loi, san	Boi loi	2	2	2	2	50	10	2	6.6	20	693	1	0	1300	3433
A9	Boi loi, san	Boi loi	3	1	1	2	70	0	2	6.7	0	691	1	0	1367	2333
A10	Boi loi, san	Boi loi	1	2	2	2	75	10	2	6.3	0	691	1	0	1733	5900
A11	Boi loi, san	Boi loi	5	1	1	2	50	20	2	6.6	10	673	1	5	900	1100
A12	Boi loi, san	Boi loi	3	1	1	2	50	10	2	6.2	15	673	2	5	1233	1433
B1	Boi loi, san	Boi loi	4	2	3	2	80	5	3	6.2	0	699	1	0	500	1500
B2	Boi loi, san	Boi loi	7	1	1	2	15	10	2	5.7	20	666	1	0	1367	1733
B3	Boi loi, san	Boi loi	6	1	1	2	0	10	2	5.5	0	669	1	2	1967	2367
B4	Boi loi, san	Boi loi	5	1	1	2	80	10	2	6.4	10	678	1	0	500	500
B5	Boi loi, san	Boi loi	7	1	1	2	7	7	2	6.2	10	674	1	0	1367	1533
B6	Boi loi	Boi loi	4	2	2	1	0	5	2	6.4	10	669	1	2	1133	3600
B7	Boi loi, san	Boi loi	2	2	2	2	65	5	2	6.4	7	698	1	0	1000	2800
B8	Boi loi	Boi loi	4	1	1	1	0	20	2	6.5	10	718	1	0	1700	1733
B9	Boi loi, san	Boi loi	3	2	2	2	15	15	2	6.6	5	716	1	0	1000	2900
B10	Boi loi	Boi loi	5	1	1	1	0	45	2	6.6	10	720	1	0	1100	1100

Plot code	Dg cm	Hg m	Mean crown area m2	Volume m3	Cost for Litsea/ha	Mean price of Litseae (VND/tree)	Income from Litsea/ha (VND)	Productivity of cassava ton/ha	Income from cassava /ha (VND)	Total income VND/ha	Total fee VDD/ha	Profits /ha (VND)	Fresh biomass stem kg	Fresh biomass bark kg	Fresh biomass leaf kg	Fresh biomass branch kg	Fresh biomass of tree kg
A1	6.5	5.4	2.1382465	0.012293	-	30,000	48,600,000	-		48,600,000	-	48,600,000	8.8	4.3	4.6	3.0	20.7
A2	6.7	4.6	2.010619298	0.011906	-	25,000	43,333,333	-		43,333,333	-	43,333,333	8.1	4.0	3.5	4.0	19.6
A3	6.2	4.6	1.767145868	0.009817	-	25,000	31,666,667	5.0	3,000,000	34,666,667		34,666,667	6.3	3.4	3.0	2.6	15.3
A4	3.3	2.9	2.269800692	0.002724	-	-	-	-	-	-	-	-	2.0	1.1	2.2	1.4	6.7
A5	1.1	1.6	1.5393804	0.000550	-	1,000	5,033,333	7.0	4,200,000	9,233,333	-	9,233,333	0.5	0.2	1.0	0.4	2.0
A6	6.5	4.8	2.83528737	0.009437	-	15,000	30,000,000	2.5	1,500,000	31,500,000	-	31,500,000	7.0	2.8	2.6	3.3	15.7
A7	3.5	3.3	3.141592654	0.002787	-	4,000	7,733,333	5.0	3,000,000	10,733,333	-	10,733,333	2.2	0.9	1.7	1.5	6.3
A8	2.1	2.0	2.83528737	0.001165	-	1,000	3,433,333	3.5	2,100,000	5,533,333	-	5,533,333	0.9	0.3	1.0	0.8	3.0
A9	3.0	2.6	1.130973355	0.001764	-	3,000	7,000,000	4.0	2,400,000	9,400,000	-	9,400,000	1.3	0.7	0.5	0.4	2.8
A10	1.0	1.6	0.785398163	0.000502	-	1,000	5,900,000	3.5	2,100,000	8,000,000	-	8,000,000	0.4	0.1	0.3	0.2	0.9
A11	5.2	3.9	1.5393804	0.006422	-	25,000	27,500,000	1.5	900,000	28,400,000	-	28,400,000	4.5	2.5	2.8	1.9	11.6
A12	3.5	2.9	1.767145868	0.002438	-	5,000	7,166,667	1.0	600,000	7,766,667	-	7,766,667	1.6	1.0	1.3	1.0	4.8
B1	5.4	3.6	1.583676857	0.006646	-	20,000	30,000,000	8.0	4,800,000	34,800,000	-	34,800,000	4.0	2.1	2.1	1.5	9.7
B2	5.1	3.4	3.801327111	0.006338	800,000	25,000	43,333,333	1.0	600,000	43,933,333	800,000	43,133,333	3.7	2.3	2.8	2.4	11.2
B3	4.7	4.3	1.767145868	0.005621	700,000	20,000	47,333,333	-	-	47,333,333	700,000	46,633,333	3.5	2.0	1.8	1.6	8.8
B4	3.6	2.7	2.544690049	0.002040	500,000	8,000	4,000,000	13.3	8,000,000	12,000,000	500,000	11,500,000	1.5	0.7	1.2	0.7	4.1
B5	7.0	4.8	2.986476516	0.010876	1,100,000	35,000	53,666,667	0.6	360,000	54,026,667	1,100,000	52,926,667	7.6	4.0	4.7	3.1	19.3
B6	5.2	4.3	7.068583471	0.006306	-	5,000	18,000,000	-	-	18,000,000	-	18,000,000	4.2	1.6	2.8	2.5	11.1
B7	2.4	1.8	2.83528737	0.000869	-	-	-	3.0	1,800,000	1,800,000	-	1,800,000	0.7	0.4	1.1	0.6	2.8
B8	5.7	3.6	2.83528737	0.005895	-	10,000	17,333,333	-	-	17,333,333	-	17,333,333	4.3	1.7	1.7	2.8	10.5
B9	2.4	2.1	2.83528737	0.000914	-	-	-	13.3	7,980,000	7,980,000	-	7,980,000	0.8	0.3	1.0	0.6	2.7
B10	6.5	3.3	3.63050301	0.007610	-	17,000	18,700,000	-	-	18,700,000		18,700,000	6.3	1.9	3.7	4.1	16.0

Plot code	Dry biomass of stem kg	Dry biomass of bark kg	Dry biomass of leaf kg	Dry biomass of branch kg	Dry biomass of tree kg	% SK dry/fresh stem	% SK dry/fresh bark	% SK dry/fresh leaf	% SK dry/fresh branch	% SK dry/fresh tree	% C in dry sample stem	% C in dry sample bark	% C in dry sample leaf	% C in dry sample branch	% C in dry sample tree
A1	4.5	1.3	1.8	1.2	8.7	50.9	29.6	39.1	38.4	42.0	48.1	47.5	48.8	47.7	48.1
A2	4.2	1.4	1.3	1.4	8.2	51.9	33.9	35.9	35.4	42.0	46.8	45.2	50.1	46.7	47.2
A3	3.0	1.0	1.1	1.0	6.2	47.7	30.2	37.3	39.0	40.3	46.6	43.9	49.9	47.5	47.1
A4	1.0	0.4	0.8	0.5	2.7	47.6	34.6	37.5	37.8	40.1	47.0	45.7	45.8	48.6	46.8
A5	0.2	0.0	0.3	0.1	0.7	42.2	26.5	33.3	31.3	34.4	49.2	46.2	48.8	47.6	48.1
A6	3.4	0.8	1.0	1.2	6.5	48.6	28.6	39.1	37.3	41.1	47.6	44.8	49.7	47.4	47.6
A7	1.1	0.3	0.7	0.6	2.6	49.8	31.7	38.8	38.4	41.5	47.9	45.1	47.5	45.4	46.6
A8	0.4	0.1	0.4	0.3	1.1	45.2	29.2	38.3	35.9	38.9	48.4	45.8	50.2	48.8	48.4
A9	0.6	0.2	0.2	0.1	1.1	46.0	32.4	41.6	40.5	41.4	47.2	45.8	50.8	49.0	48.3
A10	0.1	0.0	0.1	0.0	0.3	33.1	22.0	31.9	26.6	30.1	45.2	45.6	46.8	46.7	46.1
A11	2.4	0.8	1.3	0.8	5.3	52.7	33.2	46.1	42.0	45.3	49.8	46.1	49.9	50.4	49.3
A12	0.7	0.3	0.5	0.4	1.9	46.4	29.1	37.8	39.6	39.3	49.2	47.1	48.1	48.8	48.4
B1	1.7	0.5	0.8	0.5	3.6	43.3	25.0	40.3	32.9	37.1	48.0	45.2	48.6	48.0	47.7
B2	1.7	1.0	1.1	1.1	4.9	47.3	41.5	40.6	44.0	43.7	49.0	46.5	50.1	50.2	48.9
B3	1.8	0.7	0.7	0.6	3.8	51.8	36.1	37.8	38.8	43.1	48.1	43.4	47.1	47.1	46.6
B4	0.7	0.2	0.4	0.3	1.5	45.4	26.8	34.5	38.7	37.9	48.1	45.6	48.8	45.7	47.2
B5	3.8	1.3	1.9	1.2	8.1	49.7	32.4	40.1	38.7	42.1	46.3	44.7	48.6	45.9	46.5
B6	1.9	0.4	1.0	0.9	4.2	46.1	26.3	36.1	35.2	38.3	47.5	46.1	48.6	46.3	47.2
B7	0.3	0.1	0.4	0.2	1.0	41.3	26.7	35.6	37.5	36.1	48.1	45.8	49.2	46.6	47.5
B8	2.0	0.6	0.7	1.1	4.3	46.4	33.3	41.4	39.3	41.6	50.7	48.0	49.2	46.7	48.8
B9	0.3	0.1	0.4	0.2	1.0	40.0	28.5	38.7	32.6	36.6	48.8	47.7	50.7	49.4	49.2
B10	3.1	0.7	1.5	1.7	6.9	48.6	35.6	40.6	40.4	43.1	49.2	46.7	45.8	47.9	47.5

Plot code	% C in fresh biomass than	% C in fresh biomass bark	% C in fresh biomass leaf	% C in fresh biomass branch	% C in fresh biomass tree	Weight of C in stem kg	Weight of C in bark kg	Weight of C in stem la kg	Weight of C in branch kg	Weight of C in tree kg
A1	24.5	14.1	19.1	18.3	20.2	2.2	0.6	0.9	0.6	4.2
A2	24.3	15.3	18.0	16.5	19.8	2.0	0.6	0.6	0.7	3.9
A3	22.2	13.3	18.6	18.5	19.0	1.4	0.5	0.6	0.5	2.9
A4	22.4	15.8	17.2	18.4	18.8	0.4	0.2	0.4	0.3	1.3
A5	20.7	12.2	16.2	14.9	16.5	0.1	0.0	0.2	0.1	0.3
A6	23.1	12.8	19.4	17.7	19.5	1.6	0.4	0.5	0.6	3.1
A7	23.8	14.3	18.4	17.4	19.3	0.5	0.1	0.3	0.3	1.2
A8	21.9	13.4	19.2	17.5	18.8	0.2	0.0	0.2	0.1	0.6
A9	21.7	14.8	21.1	19.9	20.0	0.3	0.1	0.1	0.1	0.5
A10	15.0	10.0	14.9	12.4	13.9	0.1	0.0	0.0	0.0	0.1
A11	26.2	15.3	23.0	21.2	22.3	1.2	0.4	0.6	0.4	2.6
A12	22.8	13.7	18.2	19.3	19.0	0.4	0.1	0.2	0.2	0.9
B1	20.8	11.3	19.6	15.8	17.7	0.8	0.2	0.4	0.2	1.7
B2	23.2	19.3	20.3	22.1	21.4	0.8	0.4	0.6	0.5	2.4
B3	24.9	15.7	17.8	18.3	20.1	0.9	0.3	0.3	0.3	1.8
B4	21.9	12.2	16.8	17.7	17.9	0.3	0.1	0.2	0.1	0.7
B5	23.0	14.5	19.5	17.8	19.6	1.8	0.6	0.9	0.5	3.8
B6	21.9	12.1	17.6	16.3	18.1	0.9	0.2	0.5	0.4	2.0
B7	19.9	12.2	17.5	17.5	17.1	0.1	0.0	0.2	0.1	0.5
B8	23.5	16.0	20.3	18.4	20.3	1.0	0.3	0.3	0.5	2.1
B9	19.5	13.6	19.6	16.1	18.0	0.2	0.0	0.2	0.1	0.5
B10	23.9	16.6	18.6	19.3	20.5	1.5	0.3	0.7	0.8	3.3

Codes:

Seed	1	Without cassava	1	Yellowish brown	1	Flat	1
Shoot	2	With cassava	2	Reddish brown	2	Hillside	2
				Black grey	3		