WORLD CONGRESS ON AGROFORESTRY 2014
10-14 FEBRUARY 2014, DELHI, INDIA
Trees for Life: Accelerating the Impact of Agroforestry

CO_2 SEQUESTRATION ESTIMATION FOR THE LITSEA - CASSAVA AGROFORESTRY MODEL IN THE CENTRAL HIGHLANDS OF VIETNAM

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Abstract
The Litsea - Cassava agroforestry model has been popularly practiced in the Central Highlands of Vietnam, 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; 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. In order to estimate the environment value of stored carbon of this model, the experimental method for involves: sample plot, destructive sampling, 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. 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. Within cycle of 2 and 3 of this model, maintaining 2-3 shoots/stump of Litsea will have the greatest effect not only on productivity, but also on absorbed CO_2 .

Key words: *Agroforestry, Cassava, CO_2 sequestration, Litsea glutinosa.*

1 INTRODUCTION

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.

Figure 1: *Agroforestry model of Lisea-Cassava in the study site*

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

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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 (showed in figure 1). 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. 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.

In order to estimate biomass and carbon of forest, in some developed countries, tree allometric equations are available for most of their forest tree species. In the United States, Jennier (2004) had compiled more than 1,700 allometric equations for more than 100 species of trees from 177 sample trees, mainly estimating biomass based on DBH as predictor. Brown (1989 – 2001) summarized models of allometric equations developed for tropical areas around the world including dry forest, moist forest, swamp forest and coniferous forest. Data sources were from a variety of trees destructively sampled from three tropical zones with a total of 371 sample trees with diameter ranging 5-148 cm. Of these models, the model developed for moist forests can be applied to low mountainous evergreen broad-leaved forests of Viet Nam, considering the similarity of site conditions (i.e. average rainfall 1,500-4.000 mm, with one dry season during the year). Chave et al., (2005) synthesized results of 27 published and unpublished data sources of sample trees which were destructively sampled to measure forest above ground biomass (AGB) from the three continents of America, Asia, and Oceania. The total number of sample trees was 2,410 with DBH of 5 cm – 150cm.

The models mentioned above were made based on limited data not collected in Viet Nam, nor assessed for relevance and reliability in the rainforest conditions of Viet Nam. Hence they should assess accuracy and reliability. Several generic models have been developed for the tropical forests and can be compared to the newly developed and country specific equations. Also, it is noteworthy that Ketterings et al., (2001) has suggested that the biomass models of Brown (1989) based on 168 sample trees may not be representative of the diversity of tree species as well as different types of tropical forests.

The estimation of biomass and carbon of agroforestry models poorly studied. MacDicken 1997 developed only the guideline for measurements of biomass, carbon of agroforestry in general. Lack of development of allometric equations for the common forest tree species in agroforestry systems in the different ecological regions as well as equations to estimate total biomass, carbon for agroforestry systems.

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. Therefore, the research aimed to construct models for biomass estimation and CO_2 sequestration of *Litsea glutinosa* in the Litsea–Cassava agroforestry model.

2 MATERIALS AND METHODS

2.1 Research object

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

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.

2.2 Description of research area

Research location

The research is carried out in Gia Lai province of the Central Highlands of Vietnam. It is located with coordination: $12^0$58’59” – $14^0$34’18” N and $107^0$19’15” – $108^0$42’44” E.

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. The rainy season is from May to October. The mean annual rainfall is 2,200 mm. 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.

2.3 Research methods

2.3.1 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: sample plot, destructive sampling; 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.

2.3.2 Method of sampling and data collection

Litsea sample plots: A total of 22 circular plots, each with an area of 300 m^2 were 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 (DBH), tree height (H), and crown area (CA).

Destructive sampling: Select an average tree in the forest stand for each sample plot 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 datat collection and 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 100g for analysis to estimate the dry biomass and carbon pool in each component (showed in figures 2 and 3). There were 22 sample trees with 88 component samples used to determine the stored carbon content in Litsea.

Figure 2: *Weighing to define the fresh biomass of the four componenets of Litsea: stem, branches, leaves, and bark*

Figure 3: *Sampling of the four componenets of Litsea to analyze carbon pools in the stem, branches, leaves, and bark*

2.3.3 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 105ºC 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 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 %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 was calculated. The CO_2 concentration based on an average tree was transformed by the equation: $CO_2 = 3.67C$.

Multivariable regression analysis yi = f(xj): In order to estimate the biomass of the tree, numerous publications have suggested power models are suitable for building allometric equations based on one or more variables (Pearson, 2007). Some authors used the second order exponential function of parabolic as Brown (1989, 1997). Basuki et al., (2009) used the model of dipterocarp forest biomass to compare the higher-order parabolic functions of Brown (1989), Chave (2005), Huy et al. (2012) using average deviation, and the result indicated the transformed exponential function as below gave smaller deviation and higher reliability. All allometric equations established mainly for tree individual.

In this research, modeling of relationships between biomass, stored carbon and absorbed CO_2 was carried out using inventory data from the average tree and stand age (A), average DBH (Dg), average of heigh (Hg), density of Litsea per ha (N), shoot density/ha, and the average number of shoots. Multiple-regression with transformed factors was used to develop allometric equation for estimating biomass and carbon sequestration of agroforestry model.

3 RESULTS AND DISCUSSIONS

3.1 Ratios of carbon stored in the biomass of Litsea

Figure 4 indicated that 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%. This rate is*

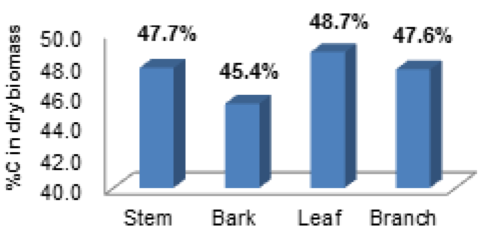

Figure 4: *%C in the dry biomass of the tree components of Litsea.*

consistent with the conversion of biomass into carbon of IPCC (2006) is 0.47.

3.2 Estimates of 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 dry biomass was indirectly estimated through model construction.

Developed allometric equations to estimate the dry biomass of the tree components and for the whole tree are based on Dg (Quandratic stand diameter), which is easier and cheaper to measure showed in the table 1.

Table 1: *Allometric equations to estimate the dry biomass of the components and for an average Litsea tree*

Allometric equations based on Dg	**R^2**	**P**	**Equation**
log(stem dry biomass kg) = -2.31337 + 1.81765*log(Dg cm)	0.935	0.00	1
log(bark dry biomass kg) = -3.68511 + 1.94248*log(Dg cm)	0.929	0.00	2
log(leaf dry biomass kg) = -2.02567 + 1.19235*log(Dg cm)	0.759	0.00	3
log(branch dry biomass kg) = -2.85803 + 1.59805*log(Dg cm)	0.871	0.00	4
log(tree dry biomass kg) = -1.16425 + 1.60676*log(Dg cm)	**0.923**	**0.00**	**5**

log = Napier logarithm.

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.*

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

The results above including biomass allometric equations and conversion factor from biomass to carbonb 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. Developed allometric equations to estimate carbon sequestration in tree components showed in table 2.

Table 2: *Allometric equations to estimate the carbon sequestration of the components and for an Litsea average tree*

Allometric equations based on Dg	**R^2**	**P**	**Equation**
log(C of stem kg) = -3.05514 + 1.8237*log(Dg cm)	0.963	0.00	6
log(C of bark kg) = -4.45754 + 1.93655*log(Dg cm)	0.931	0.00	7
log(C of leaf kg) = -2.74975 + 1.19657*log(Dg cm)	0.764	0.00	8
log(C of branch kg) = -3.59605 + 1.59554*log(Dg cm)	0.870	0.00	9
log(C of the whole tree kg) = -1.90151 + 1.60612*log(Dg cm)	0.922	**0.00**	**10**

log = Napier logarithm

The results in table 2 indicated 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.*

3.4 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.

Table 3 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 (N); and c) quadratic stand diameter of Litsea (Dg).*

Table 3: *Regressions for predictions of biomass and stored carbon in Litsea in the Litsea-Cassava model*

Regressions	R^2	**P**	**Equation**
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	11
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	12

Remark: 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.

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 equation 11 and 12 in table 3, 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 3 for the variables shoots/stump, N/ha and Dg was considered constant, so the required number of shoots/stump to achieve the greatest 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/ha + b_4. *Dg

The specific derivative for the number of shoots was equated to zero:

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

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

$$Optimal\ number\ of\ \frac{shoots}{stump} = \frac{b1}{2b2} = \frac{2.489}{2*0.500} = 2.5$$

The result indicated that the average number of shoots was 2.5 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.*

Table 4 below shows the CO_2 sequestration predicted by allometric equation 12 in the model for the number of optimal shoots/stump = 2 and an average Litsea density of 1300 trees/ha. In with CO_2 calculated = 3.67C.

Table 4*: Predicted CO_2 sequestration of the Litsea-Cassava agroforestry model according to business cycle.*

A (year)	Number of Litsea shoots /stump	N/ha	Dg (cm)	CO_2/ha concentrated by Litsea (ton/ha)
2	2	1300	2.4	6.3
3	2	1300	3.6	10.9
4	2	1300	4.6	17.0
5	2	1300	5.4	24.7
6	2	1300	6.0	33.8
7	2	1300	6.6	44.4
8	2	1300	7.1	56.4
9	2	1300	7.6	69.7
10	2	1300	8.0	84.2

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. Therefore, if there will be a policy to encourage the development of agroforestry based on payment for the amount of CO_2 concentrated, farmers would increase their income and the model also absorb CO_2 amount significantly.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 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 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 6 to 84 tons, increasing with age.
iii) 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.

4.2 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.
ii) 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.

Acknowledgments

This research has been granted by Swedish International Development Cooperation Agency (SIDA) through managed by the World Agroforestry Center (ICRAF) and coordinated by SouthEast Asian Network for Agroforestry Education (SEANAFE). Author would like to take this opportunity to thank these agencies for their valuable support and advice.

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