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Estimation of aboveground tree biomass *Toona sureni* and *Coffea arabica* in agroforestry system of Simalungun, North Sumatra, Indonesia

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Abstract. *Latifah S, Muhdi, Purwoko A, Tanjung E. 2018. Estimation of aboveground tree biomass* Toona sureni *and* Coffea arabica *in agroforestry system of Simalungun, North Sumatra, Indonesia. Biodiversitas 19: 670-675.* Agroforestry is an ecologically and environmentally sustainable land use that offers great promise to carbon (C) sequestration. Forests play a significant role in reducing greenhouse gas emissions through maintaining current carbon stores and by increasing the rate of carbon sequestration. Vegetation carbon stocks are necessary to be quantified to evaluate the carbon sequestration potential in the ecosystem. Reasonable methods for estimating tree biomass and carbon storage on forest land are increasingly crucial given concerns of global climate change. This study aimed to evaluate C sequestration potential by agroforestry in North Sumatra Indonesia. This study was conducted at the Agroforestry system in Aek Nauli, Simalungun District, North Sumatra. Data collection for primary data was done through a field survey. The present study was carried out to determine above ground tree biomass of *Toona sureni* (Blume) Merr and *Coffea arabica*. Data retrieval of *T. sureni* and *C. arabica* was done by non-destructive sampling by measuring the diameter at breast height (dbh). The results showed that the potential of average above-ground biomass and carbon storage of *T. sureni* and *C. arabica* was 6.25 t ha^{-1} and 2.88 C t ha^{-1}, respectively. Total aboveground biomass of *Toona sureni* and *C. arabica* in the study area was 93.75 ton, while total of carbon storage was 43.16 ton

Keywords: Above ground, carbon sequestration, *Coffea arabica*, *Toona sureni*

INTRODUCTION

One of the efforts to minimize impacts of climate change is by stabilizing the CO_2 concentration in the atmosphere. This is related to forest ability to absorb CO_2 from the atmosphere and then store it in forest stand in the form of organic matter or plant biomass (Watson et al. 2000). Live tree biomass estimates are essential for carbon accounting, bioenergy feasibility studies, and other analyses (Chauhan et al. 2010)

Information gathered in forest inventories in the tropics usually includes only tree diameter at breast height and commercial height. Commercial tree height, in many cases, is difficult to be accurately measured. Biased estimates will occur when tree height is included as an independent variable in volume and biomass models. Therefore, it is essential to develop volume and total aboveground biomass estimation models using variables, such as diameter at breast height,which can be accurately measured in the field. This method is fast, requiring less work, and is, therefore, cost-efficient in forest inventories (Yuen et al. 2016). The most common procedure used for estimating individual tree biomass is mathematical models calculated by regression analysis (Latifah and Sulistiyono 2013).

The *C. arabica* is cultivated typically in agroforestry systems in close association with a rich list of tree species and other useful plants on the same plot. Coffee-based agroforestry systems are credited for stocking significant amounts of carbon and hence have the potential to mitigate climate change. Most of the people who live in the Aek Nauli have cultivated their land by cultivating crops with *T. sureni* Merr. and *C. arabica.* In North Sumatra, the natural conditions are the most favorable for *T. sureni. T. sureni* is known by its local name in Burmese (ye tama); English (suren toona.red cedar); Filipino (danupra); Indonesian (suren); Malay (surian wangi); Thai (surian); and trade name (toon.surian, red cedar.limpaga). *T. sureni* is a medium-sized to fairly large tree of up to 40 (60) m tall and diameter of up to 100 cm (300 cm in mountainous areas) with dark brown young branches. The bole is branchless for up to 25 m and buttressed up to 2 m. (Sahana et al. 2012).

Forest ecosystems contain over 45% of carbon in terrestrial biosphere and thus play a leading role in the globe carbon cycle (Beer et al. 2010). An accurate estimate of ecosystem C storages in forests is crucial for predicting the national carbon-climate feedback and guiding the implementation of mitigation policies (Beer et al. 2010; Pan et al. 2011; Yang et al. 2014). This paper presents results from growth measurement in plots of agroforestry. Data also provide an immediately useful description of the tree using conventional parameters (e.g., diameter, volume and dimensional relationship for individual trees, e.g., volume or biomass or carbon storage with diameter). Accurate estimates of forest carbon storage and changes in storage capacity are critical for scientific assessment of the effects of forest management on the role of forests as carbon sinks. This study aimed to evaluate C sequestration potential by agroforestry in North Sumatra Indonesia.

MATERIALS AND METHODS

Study area

The research location is situated at the agroforestry systems of Forestry Research Institute of Aek Nauli, located in the Simpang Girsang Bolon Sub District, Simalungun District, North Sumatra Province, Indonesia. Research was conducted in December 2015 and July-August 2016. This forest has a slope of 2 to 15% and partly a flat area of the hilly and partly a shallow valley. Rainfall of Aek Nauli area belong to the type A according to Smith and Ferguson classification with an average rainfall of 2199.4 mm and the average monthly temperature ranged from 23 to 24°C.

Data collection and analysis

Determination of biomass production from indigenous Agroforestry System is a challenging task and makes extrapolation from one system to others very difficult. Research activities were focused on Estimating Above Ground Tree Biomassof *T. sureni* and *C. arabica.*Equipment used in this research included measuring tape, Clinometers, tally sheet, digital cameras, calipee, raffia rope, GPS (Global Positioning Systems), a compass, a wooden cane/bamboo, machetes, and stationery. Materials used in this research were *T. sureni* and *C. arabica* in the Forestry Research Institute of Aek Nauli Simalungun.

Measurement plot (PU) used in this study had the size of 40 m × 5 m. Placement of PU was conducted by *systematic random sampling*. There were 15 random sampling plots with a total area of 3.000 m^2. The collected data comprised of diameter at breast height for *T. sureni* and *C. arabica* (dbh) and number of tree in the plots.

The typical methods for measuring biomass are destructive methods, which prevents the development of individual plants to be followed and require many individuals to be cultivated for repeated measurements. Non-destructive methods do not have these limitations. Here, a non-destructive method was done in this research. Biomass of trees in the plot was determined by analyzing the data using allometric equation. Model equation for the volume of *T. sureni* according to Haruni et al. (2012) is as presented below :

$$VK = 0.00013\ D^{2.057} \quad [1]$$

Where:
D = diameter at breast height (dbh-cm);
VK = volume (m^3)

To convert a volume value of the trees into the value of above ground tree biomass, volume value obtained from the model tree allometric volume was multiplied by the density of the wood (wood density) that is equal to 390 kg m^{-3} (P3HH, 2008). This can be expressed as:

$$\text{Biomass} = VK \times 390\ kg/m^3 \quad [2]$$

Allometric equation model for coffee plant according to Arifin (2001) is as follow:

$$(AGB)est. = 0.281\ D^{2,06}$$
(AGB)est. = above ground biomass (kg/tree) [3]

D = DBH (diameter at breast height) (cm)

Biomass per unit area is calculated as follows:

$$\text{Biomass per unit area} = \frac{\text{Total biomass (g)}}{\text{Area (m)}^2} \quad [4]$$

Forest biomass could be used to estimate carbon content within forest vegetation because 46% of the biomass is composed of carbon. Carbon content was estimated by the following formula (Hairiah and Rahayu, 2007):

$$C = B \times 0.46 \quad [5]$$

Where:
C = amount of carbon stock (t C ha^{-1})
B = biomass (t ha^{-1})
0.46 = carbon content

Carbon sequestration (CO_2) could be estimated by the following formula (Bismark et al. 2008):

$$\text{Sequestration of } CO_2 = \frac{Mr\ CO2}{Ar\ C} \quad [6]$$

$$\text{Sequestration of } CO_2 = 3.67 \times \text{carbon content} \quad [7]$$

Where:
Mr = molecule relative
Ar = atom relative

RESULTS AND DISCUSSION

Carbon sequestration is the capture of atmospheric CO_2 into green plants, which is stored for a long time. The natural storage of CO_2 by above ground biomass (trees), under storey vegetation and below ground parts (roots and micro-organisms) is one of the effective techniques for mitigating the atmospheric CO_2 levels (Jina et al. 2009).

The results showed that the study site of agroforestry was 3.000 m^2 or 0.3 ha. Spacing in this study for *T. sureni* and *C. arabica* were 3 m x 2 m and 1.5 m x 1.5 m, respectively. The data were set for estimating the biomass from 300 *T. sureni* trees and 238 *C. arabica* plants. In the Forestry Research Institute of Aek Nauli type of agroforestry in the study included simple agroforestry, i.e., a crop associated with a tree while complex agroforestry systems in terms of structure, with multi-strata components, a large biodiversity in terms of species and frequencies, where several perennial crops and trees are associated.

Most communities in the research area chose agroforestry because it is profitable, biologically productive and sustainable. In the study site, forests are established in the modification of wind flow and microclimate to the surrounding land and harvest fields. These look like borders along land plots and can act as fences, pesticide barriers, and even odor-drift barriers. In this case, *T. sureni* was used as a protective stand (shelter), and the coffee crop was planted as a farm crop. The stands also serve as a fence around the plots of crops, randomly spread in the field, or with other patterns, for example, *T. sureni* lined up in an array so as to form a hallway/fence.

Descriptive statisticsof stand variables

T. sureni and *C. arabica* data were collected on plants of 15 years old within randomly placed measurement plots. Results of data analysis showed a correlation value between diameter and height of *T. sureni* plants of 0.65, indicating a close relationship between the two parameters. Based on this high correlation value, either one of the two variables can be used to estimate the tree biomass. Either the diameter or height of a tree is an independent variable whereas tree biomass is a dependent variable. According to Baker et al. (2002), choice of diameter at breast height (dbh) as an independent variable would improve the efficiency and reduce the uncertainty of measurement result on the basis of the established equation. Meanwhile, the choice of tree height as an independent variable tended to reduce measurement efficiency because the tree height is more difficult to measure than the diameter at breast height.Performance of *T. sureni* and *C. arabica* inanagroforestry system can be seen in Figure 1.

The descriptive statistics summary of the diameter, biomass, and carbon storage are shown in Table 1. Results show that *T. sureni* had the highest average diameter of 25.1 cm, the lowest average diameter of 6.45 cm and the average diameter of 10.87 cm, while *C. arabica* had the highest average diameter of 7.2 cm, the smallest average diameter of 1.05 cm and the average diameter of 3.2 cm. *T. sureni* had the variances of diameter, biomass and carbon storage, respectively,of 2.69, 18.88, and 4. The standard deviations of the stand diameter, biomass, and carbon storage are, respectively, 1.81, 3.83 and 1.76. The variance of diameter, biomass and carbon storage of *C. arabica* had are, respectively, 2.1, 0.09 and 0.02. Meanwhile, the standard deviations of the stand diameter, biomass and carbon storage of *C. arabica* are 1.46; 2.6 and 1.8, respectively.

Table 1. Descriptive statistics for diameter, biomass and carbon storage of *Toona sureni* and *Coffea arabica*

Descriptive statistics	Diameter (cm)	Biomass (t ha^{-})	Carbon storage (C t ha^{-1})
T. sureni			
max	25.10	14.10	6.49
min	6.45	0.84	0.39
average	10.87	5.24	2.41
variance	2.69	18.88	4.00
stdev	1.81	3.83	1.76
C. arabica			
max	7.20	1.10	0.55
min	1.05	0.18	0.08
average	3.20	0.69	0.32
variance	1.03	0.09	0.02
stdev	1.46	2.57	1.83

Figure 1. *Toona sureni* (A) and *Coffea arabica* (B) in agroforestry system of the study site

The potency of biomass and carbon storage

Biomass constitutes the amount of organic matter produced by an organism per unit area at a particular time (Zianis et al. 2005). Biomass could be classified into two categories, namely above ground biomass and below ground biomass. This research was focused on above ground biomass estimation. Biomass was measured on the basis of dry weight because of the prevailing variability of water content in each plant. Unit of biomass measurement was gram per m^2 or kg per ha (Kumar and Nair, 2011). The general allometric model was selected and used to estimate biomass per tree by using data of stem diameter (Equations 1 and 2). Density, diameter interval, average diameter and the estimated biomass (using equation 1 and 2) of *T. sureni* are shown in Table 2.

Estimation of stand biomass at various land unit systems in Indonesia has frequently been conducted. Biomass and carbon storage of *T. sureni* in the present study ranged from, respectively, 0.84 to 14.10 t ha^{-1} and 0.39 to 6.49C t ha^{-1}. Research results showed that average biomass of *T. sureni* stand at ages of 15 years was 5.24 ton ha^{-1}. On the other hand, the average carbon potency of *T. sureni* stand was 2.41 C t ha^{-1}. In this study area, total aboveground biomass was 83.45 ton, and the total of carbon storage was 38.42 ton. Table 2 indicates that *T. sureni* has the highest average biomass of 14.1 ton ha^{-1} at plot number 4 and the lowest average biomass of 0.84 14.1 ton ha^{-1}at plot number 6. Carbon storage of *T. sureni* was highest (6.49 C ton ha^{-1}) at plot number 4 and lowest (0.39 C ton ha^{-1})at plot number 6. Plot number 4 showed the highest in both tree biomass and carbon storage since this plot contained the highest number of trees $plot^{-1}$ (45 trees $plot^{-1}$). The amount of organic material stored in the forest biomass per unit of area and per unit of time constitutes the main issue of forest productivity. Forest productivity describes the ability of the forest to reduce CO_2 emission in the atmosphere through their physiological activities (Latifah and Sulistiyono 2013).

Density, diameter interval, average diameter, estimated biomass (calculated using equation 3) and carbon storage of *C. arabica* are shown in Table 3.

The observed biomass and carbon storage of *C. arabica* ranged from, respectively, 0.18 to 1.19 $tonha^{-1}$ and 0.08 to 0.55 C t ha^{-1}. Research results showed that the average biomass of *C. arabica* stand at the ages of 2-5 years was 0.69 ton ha^{-1}. On the other hand, the average carbon potency in *C. arabica* stand was 0.32 C t ha^{-1}. In this study area, total aboveground biomass was 10.3 ton, and the total of carbon storage was 4.74 ton. Table 3 indicates that *C. arabica* has the highest average biomass of 1.19 t ha^{-1} (plot number 4) and the lowest average biomass of 0.18 t ha^{-1} (plot number 1). Carbon storage of *C. arabica* was highest (0.55 C t ha^{-1})at plot number 4 and lowest (0.08 C t ha^{-1}at plot number 1. Compared with other plots, plot number 4 had the highest average of diameter (4.14 cm), and plot number 1 had the lowest one (1.85 cm). This is caused by land use change through forestation or reforestation that increases C sequestration per unit of land. Also, the rate of C sequestered by trees within a system will depend on tree species age and density, the edaphoclimatic conditions, management, fertilization, and land clearing (Quinkenstein et al. 2009)

The potency of aboveground carbon storage could be estimated from the amount of biomass of the upper part of *T. sureni* and *C. arabica.* Table 4 shows the amount of the carbon storage of the two tree species**.** The stand range in biomass and carbon storage of *T. sureni* and *C. arabica* were 1.04 to 15.29 t ha^{-1} and 0.48 to 7.04 C t ha^{-1}, respectively. The results showed that the potential average above-ground biomass and carbon storage of *T. sureni* and *C. arabica* was 6.25 t ha^{-1} and 2.88 C t ha^{-1}, respectively. Total aboveground biomass of *T. sureni* and *C. arabica* in the study area was 93.75 ton, while the total carbon storage was 43.16 ton.

Table 2. Density, stem diameter, average diameter, estimated biomass and carbon storage of *Toona sureni* in the observed plots

Plot	Density (tree/plot)	Diameter interval (cm)	Average of diameter (cm)	Biomass ($kgplot^{-1}$)	Biomass (t ha^{-1})	Carbon storage (C t ha^{-1})
1	23	5.45-17.70	11.49	547.38	6.08	2.79
2	31	5.75-19.35	11.28	832.38	9.25	4.26
3	10	5.40-25.11	10.46	275.41	3.06	1.41
4	45	4.65-21.45	11.79	1269.13	14.10	6.49
5	10	6.75-14.91	10.42	202.94	2.25	1.04
6	6	5.60-14.15	8.17	75.66	0.84	0.39
7	19	6.50-16.35	10.98	430.86	4.79	2.21
8	25	5.30-13.21	10.34	525.23	5.84	2.69
9	19	6.35-14.75	10.81	421.71	4.69	2.16
10	29	5.55-11.81	8.65	347.56	3.86	1.78
11	18	7.11-24.10	12.25	590.53	6.56	3.02
12	27	6.11-20.05	12.93	954.68	10.61	4.88
13	12	8.10-14.10	10.49	230.55	2.56	1.18
14	16	8.21-18.85	13.42	593.77	6.61	3.04
15	10	6.41-14.61	10.63	212.24	2.36	1.08
Average	39	-	10.87	471.55	5.24	2.41
Total				6985.20	83.45	38.42

Table 3. Density, diameter interval, average diameter, estimated biomass and carbon storage of *Coffea arabica* in the observed plots

Plot	Density (tree/plot)	Diameter interval (cm)	The average of diameter (cm)	Biomass ($kgplot^{-1}$)	Biomass ($t\ ha^{-1}$)	Carbon storage ($C\ t\ ha^{-1}$)
1	14	1.10-4.60	1.85	16.19	0.18	0.08
2	13	1.05-5.25	3.52	67.14	0.75	0.34
3	23	1.05-2.95	2.07	46.75	0.52	0.24
4	19	2.05-5.85	4.14	107.23	1.19	0.55
5	29	1.40-4.60	2.26	48.33	0.54	0.25
6	12	1.50-3.85	2.15	17.61	0.20	0.09
7	25	1.20-4.65	3.12	82.36	0.92	0.42
8	13	3.00-5.55	4.22	73.24	0.81	0.37
9	16	1.95-4.35	3.27	54.17	0.60	0.28
10	25	1.65-6.35	3.45	93.77	1.04	0.48
11	11	2.20-7.2	5.01	98.21	1.09	0.50
12	14	1.05-7.05	3.18	55.41	0.62	0.29
13	9	3.15-7.1	4.31	55.86	0.62	0.29
14	8	3.5-7.15	5.01	65.59	0.73	0.34
15	7	3.05-6.35	3.61	43.70	0.49	0.22
Average			3.42	61.7	0.69	0.32
Total			51.3	925.56	10.30	4.74

Biomass and carbon potency of *T. sureni* and *C. arabica* tended to increase with the increase of plant age.Change in stand age causes a corresponding change in the stand yield. In general, the older the age of the plant, the greater the diameter of the plant.Previous studies by Baker et al. (2002) and Andre et al. (2005) showed a similar trend where plant biomass tended to increase along with the increase of tree age.

Tree C sequestration also depends on the plant species. The C sequestration of afforested or reforested lands also depends on land management and soil type. Fertilization carried out to enhance crop production in AFS indirectly increases tree growth in some edapho-climatic conditions (Dupraz et al. 2005).

Table 4. Biomass and carbon storage of *Toona sureni* and *Coffea arabica* in the agroforestry system

Plot	Biomass of *T. sureni* and *C. arabica* ($t\ ha^{-1}$)	Carbon storage of *T. sureni* and *C. arabica* ($C\ t\ ha^{-1}$)
1	6.26	2.87
2	10.00	4.60
3	3.58	1.65
4	15.29	7.04
5	2.79	1.29
6	1.04	0.48
7	5.71	2.63
8	6.65	3.06
9	5.29	2.44
10	4.90	2.26
11	7.65	3.52
12	11.23	5.17
13	3.18	1.47
14	7.33	3.38
15	2.85	1.30
Average	6.25	2.88
Total	93.75	43.16

Another factor that affects C sequestration is tree density. *P. radiata* at 833 or 2.500 trees ha^{-1} was able to sequester 40.8 and 102.4 Mg C ha^{-1} in tree roots and aboveground biomass,respectively, 11 years after plantation, despite the fact that C sequestered per tree was higher at a low density. *B. alba* planted at these densitiesalso exhibited similar results in the same area (Fernández-Núñez et al. 2010).

Physical properties or environmental condition constituted a critical factor for supporting plant growth and development. Accumulation of biomass in the tropical region is greater than that in the temperate area because photosynthesis rate in the tropical region is greater (Indriyanto 2006). Mulyana et al. (2011) found that environmental conditions, such as temperature, air humidity, soil temperature, and litter thickness were varied among various types of land cover.

Results obtained in this study and elsewhere show necessitate the development of specific biomass models for each region and forest type in the tropics. The general models of total aboveground biomass should be carefully used in particular areas or carbon project.

In conclusion, agroforestry systems have great potential to enhance C sequestration compared with tree-less agronomic systems, and therefore their implementation should be considered as a land use option in Indonesia. Carbon assessment helps associations such as farmer groups around the study sites, in improving their' income from ecological service. At present, Indonesia should be able to look at its forest potential through a different paradigm which implies that forest is not identical with wood anymore. Forests could provide services in other forms, namely playing a great role in protecting the earth atmosphere through absorption of carbon emission.

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