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# The comparison of aboveground C-stock between cacao-based agroforestry system and cacao monoculture practice in West Sumatra, Indonesia

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**Abstract.** *Santhyami, Basukriadi A, Patria MP, Abdulhadi R. 2018. The comparison of aboveground C-stock between cacao-based agroforestry system and cacao monoculture practice in West Sumatra, Indonesia. Biodiversitas 19: 472-479.* One of the main cause of climate change is deforestation for agricultural purposes. Therefore, Agroforestry System-AFS is regarded as a benign approach to reduce pressure on natural forest while still meeting the needs of local communities. In West Sumatra, Indonesia, small-scale AFS with cacao (*Theobroma cacao* L.) is the most commonly developed agroforestry system. At present, there is a tendency to intensify cacao-based AFS by reducing the shade trees leading to monoculture practice. Although many studies had demonstrated the benefits of agroforestry over monoculture, not many studies have been looking at the comparison of carbon stock (C-Stock) of cacao-based AFS with different types of shade trees, particularly in West Sumatra. This study aimed to compare the aboveground C-Stock of three types of cacao-based AFS developed in West Sumatra; (i) Cacao-Rubber (CR), (ii) Cacao Multi-strata (CM), (iii) Cacao-Coconut (CC) with monoculture practice. Using replicated nested plot design, data were collected in April-June 2017 in Pasaman District for CR and CM and Padang Pariaman District for CC and monoculture. Biomass of cacao and shade trees and saplings were determined using allometric equations. The highest total aboveground biomass and C-Stock was found in CC AFS system (an average of 206.84 Mg $ha^{-1}$ containing 103.42 MgC $ha^{-1}$, respectively). The lowest total aboveground biomass and C-Stock was found in monoculture system (an average of 20 Mg $ha^{-1}$ containing 10 MgC $ha^{-1}$, respectively). Cacao-based AFS in West Sumatra has the potential to contribute to carbon storage by increasing the stocking density of shade tress through carbon-friendly intensification. An additional incentives should be considered such as including the farmers in environmental service reward schemes for maintaining high C stocks in their farms.

**Keywords**: C-stock, agroforestry, cacao, monoculture, Sumatra

**Abbreviations:** AFS: Agroforestry System, C: Carbon, CR: Cacao-Rubber, CM: Cacao Multistrata, CC: Cacao-Coconut, M: Monoculture, dbh: diameter at breast height, d30: diameter at 30cm height

## INTRODUCTION

Climate change caused by greenhouse gases (GHG) emissions is a serious problem the world facing today. Emission comes largely from the burning of fossil energy sources and the changes of land functions, especially in the tropical rain forests. Conversion of the forest into agricultural land frees 100-200 MgC $ha^{-1}$ into the atmosphere. Southeast Asia has lost 158 thousand $km^2$ of its natural forest in the period of 2000-2012 (Hansen et al. 2013). Indonesia released emissions of 105 TgC per year between 2000-2005 (Harris et al. 2012). Up to 2014, Indonesia is the third highest emission contributing country in the world (Margono et al. 2014).

In the context of conservation, mainly related to the global warming issues, monoculture practice is assuredly not a wise option. Low biodiversity affects the ability of the ecosystem as a whole in providing environmental services. Therefore, the Agroforestry System (AFS) is one of the best approaches to reduce pressure on natural forest while still meeting local economic needs (Michon and de Foresta 1996, Nair 1998, Jose 2009). ICRAF (1993) defined agroforestry as a system and technology of land-use where annual woody plants (trees, palms, bamboo, etc.) are planted in a unit of land management together with crops and or animals in the form of spatial or time management, in which interaction of ecology and economics among the components takes place. In addition to providing economic benefits from the production of crops, AFS can provide environmental services such as carbon storage services. Therefore, AFS is recognized as an approved activity in a wide range of Land-use, Land-use Change and Forestry (LULUCF) based carbon market such as regulated carbon market (CDM), REDD+ and Voluntary Carbon Markets (VCM) (Murdiyarso and Herawati 2005; Kollmuss et al. 2008).

One of the most common crop commodities grown in AFS approach is cacao (*Theobroma cacao* L.). Cacao originally grows in tropical rain forests as under shade plant type. In South America, cacao is traditionally grown under the canopy of older primary forests, locally called *cabruca* (Sommariba et al. 2013). In addition to being grown under the forest canopy, cacao is also grown under a special shade tree from Leguminosae or fruit trees and timber with economic value as found in Sulawesi, Indonesia (Rajab et al. 2016).

In Indonesia, cacao beans are mostly produced in six provinces, i.e., South Sulawesi, Central Sulawesi, Southeast Sulawesi, West Sulawesi, North Sumatra and West Sumatra (Center for Agriculture Data and Information 2014). West Sumatra develops small-scale cacao agroforestry known as *parak*. Pasaman and Padang Pariaman Districts are two highest cacao producer regions in West Sumatra (BPS 2014). Pasaman is dominated by a multistate cacao-based AFS grown under rubber trees (*Hevea brasiliensis* Willd. ex A.Juss.). Padang-Pariaman is dominated by cacao-based AFS grown under coconut (*Cocos nucifera* L.).

The main issue in this study is the tendency of farmers who started to switch system from cacao-based AFS to monoculture. The short-term productivity of cacao-based AFS is lower than monoculture. Furthermore, in Pasaman District, there is a tendency of shifting the crop species to corn (private communication with Wali Nagari Simpati, August 2016). Although many studies that have demonstrated the benefits of agroforestry over monoculture, not many research has been looking at the comparison of carbon storage of cacao-based agroforestry with different types of shade trees, particularly in West Sumatra. This study aimed to compare aboveground C-Stock of three types of cacao-based AFS (Cacao-Rubber (CR), Cacao-Multistrata (CM), Cacao-Coconut (CC)) and monoculture practice developed in West Sumatra. Similar studies had been conducted by Rajab et al. (2016) in Sulawesi but with different composition of cacao-legumes *Gliricidia* sp. as well as cacao-multi-strata trees.

## MATERIALS AND METHODS

### Study area

The study was conducted in April-June 2017 in (i) Nagari Simpang Alahan Mati, Subdistrict of Simpang Alahan Mati (Simpati), Pasaman District, West Sumatra, Indonesia for multi-strata cacao-based AFS **(CM)** and cacao-based AFS grown under rubber plants (*H. brasiliensis*) **(CR),** and (ii) Nagari Sungai Geringging, Subdistrict of Sungai Geringging, Padang Pariaman District, West Sumatra, Indonesia for cacao-based AFS grown under coconut (*C. nucifera*) **(CC)** and cacao monoculture practice **(M)**.

*Simpang Alahan Mati, Pasaman*

Nagari Simpang Alahan Mati, Pasaman District, West Sumatra Province is about 152 km (4.5 hours drive) from the provincial capital, Padang and 20 km (0.5 hours drive) from the district capital, Lubuk Sikaping. Nagari Simpang Alahan Mati has an area of ± 49.496 ha with an altitude of 100-453 m asl. Temperature ranges between 27-30ºC with an average rainfall of 324.3 mm $year^{-1}$. The topography of Nagari Simpang Alahan Mati is a plain surrounded by hills of natural forest. Soil types in Pasaman are *lithosol* and *podzolic* (BPS Pasaman 2011).

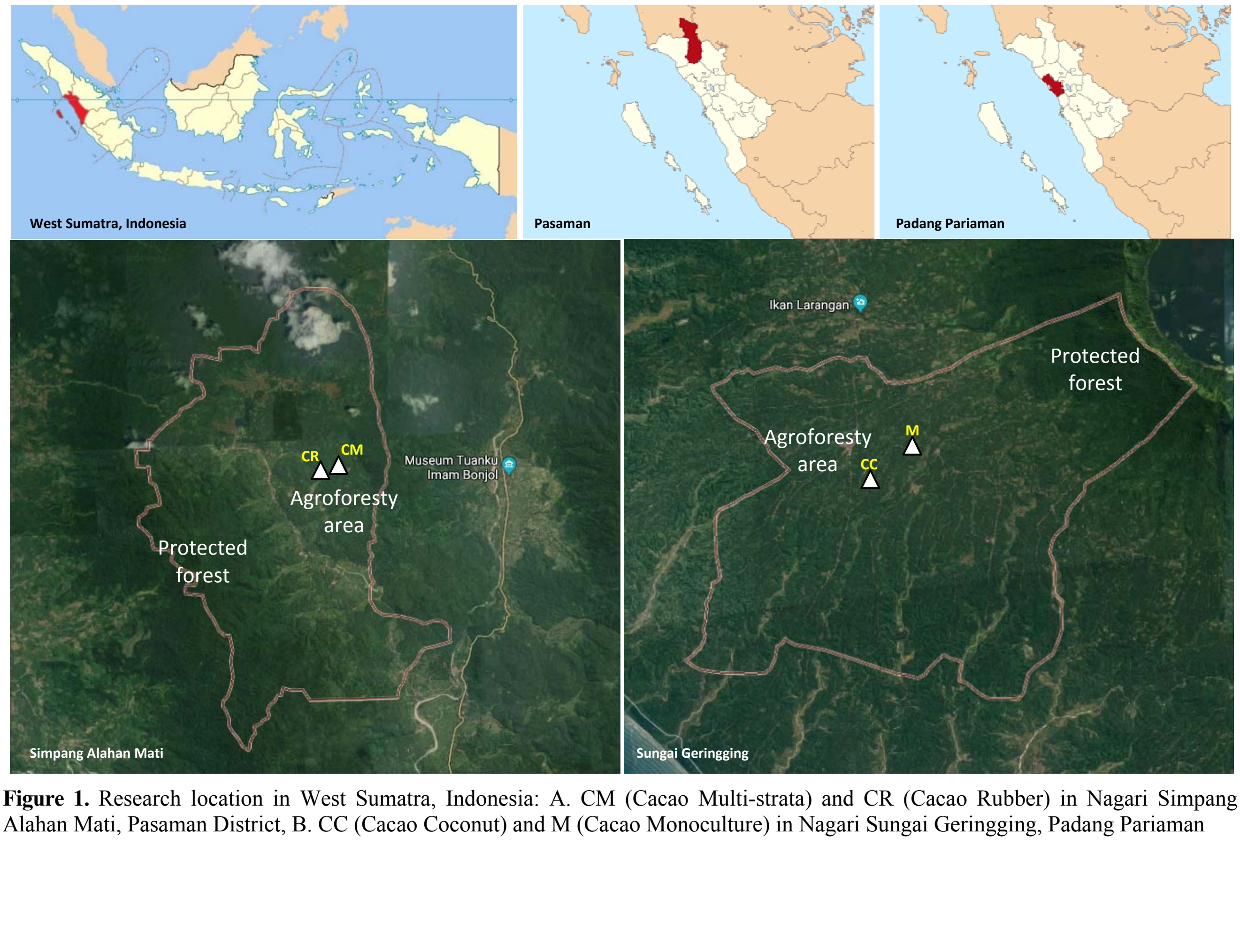


**Figure 1.** Research location in West Sumatra, Indonesia: A. CM (Cacao Multi-strata) and CR (Cacao Rubber) in Nagari Simpang Alahan Mati, Pasaman District, B. CC (Cacao Coconut) and M (Cacao Monoculture) in Nagari Sungai Geringging, Padang Pariaman

*Sungai Geringging, Padang Pariaman*

Nagari Sungai Geringging, Padang Pariaman District with an area of about 99.35 km$^2$. The average temperature was 25.49ºC, and relative humidity was 85.58%. The hottest temperatures occurred in February, while the lowest in September (BPS 2015). The overall average rainfall for Padang Pariaman Region in 2007 was 368.4 mm year$^{-1}$ with an average wind speed of 2.14 knots hour$^{-1}$. The topography of Sungai Geringging is a hilly area with an altitude of 25 m asl. Soil types are *alluvial*, *podzolic* and peat.

## Procedures

*Preliminary survey*

A preliminary survey was conducted to observe the development of cacao-based AFS and agriculture practices in those regions in general. Scheduled visits were made directly to individual farmers, farmer group, farmer group association and relevant government offices to obtain information, specifically related to cacao farming practices, location, ownership, and land area. Based on this survey, we determined the location of plots be set.

*Data collection*

**Plot design.** Plot determination was designed by a stratified sampling method. Stratification is a process of land grouping based on similar characteristics, in which case, strata are defined by the type of vegetation cover. We determined six nested plot design per land use type (Forest Works ISC 2014). The design and size of the plots were determined following BSNI (2011) that uses normative references based on COP-15 Decisions on REDD + methodology guidance (Dec. 4 / CP-15), IPCC 2006 Guidelines for National Greenhouse Gas Inventories and IPCC 2003 Good Practice Guidance for Land Use, Land Use Changes and Forestry. The size of the plots was as follows; seedlings (woody plants with leaves more than two strands and a height of ≤ 1.5m), understorey plants and litter with a minimum area of 1 m$^2$, saplings (dbh < 10 cm and a height of > 1.5m) with a minimum area of 25 m$^2$ and trees (dbh ≥ 10 cm) and debris with a minimum area of 400 m$^2$.

**Trees and saplings biomass.** All trees in the 400 m$^2$ plot and saplings in 25 m$^2$ plot were numbered. Diameter at breast height (dbh), tree crown width (WTC) and length of tree crown (LTC) of every tree and sapling, and diameter at 30 cm from the ground (d30) specifically for cacao trees were measured. Furthermore, we also measured the pseudo-diameter for bananas. On trees at the sloping location and trees that have unusual shapes, such as swollen and fork-shaped, dbh of trees and saplings was measured following the principles set by Hairiah et al. (2011)

**Seedlings and understorey plant biomass.** All seedlings and understorey plants in 1 m$^2$ plot were harvested and mixed. Fresh weight was measured, and a 300g sample was taken to measure the dry weight.

**Litter biomass.** In this study, litter is defined as tree debris with diameter <5 cm and/or 50 cm long, harvesting waste or undecomposed material such as broken twigs and fallen leaves (Hairiah et al. 2011). Litter was collected in 1m$^2$ sub-plot. All the collections were placed in a plastic bag to be washed and sieved with a 2 mm sieve and then dried in an oven at 70$^0$ C to a constant weight.

**Woody debris.** According to Hairiah et al. (2011), woody debris is all dead trees with a diameter >5 cm or a height of more than 0.5 m. To determine debris biomass, the length and diameter of debris (cm) were measured.

## Data analysis

Above ground C-Stock in one type of land use was expressed in Mg ha$^{-1}$. The total biomass in the plot (Mg ha$^{-1}$) was converted to carbon stock (MgC ha$^{-1}$). Above-ground biomass from tree stands ranging from cacao, rubber, wood and coconut trees were estimated by using an allometric approach based on dbh and d30. Some species have specific allometric equations. Table 1 shows the allometric equations used in this study.

In addition, debris biomass was calculated by using equation: Debris biomass (kg) = Volume (cm$^3$) x debris wood density ρ (g cm$^{-3}$)/10$^3$. Wood density of debris (ρ) was determined by classifying the sample into three classes of decomposition: solid wood debris (newly dead trees), rough debris (rotted trees) and fine debris (decayed trees) with debris density of 0.69, 0.34 , and 0.41 g cm$^{-3}$ respectively (Nascimento and Laurance 2002).

**Tabel 1.** Allometric equations used on the study

| Tree | Allometric equations | Source |
|---|---|---|
| *Theobroma cacao* | $AGB = 10^{(-1.625+2.63*\log(d30))}$ | Andrade et al. (2008) *in* Scroth et al. (2013) |
| *Hevea brasiliensis* | $AGB = -3.84+0.528*BA+0.001*BA^2$ | Schroth et al. (2002) |
| *Musa* sp. | $AGB = 0.03*(pdbh^{2.13})$ | vanNoordwijk et al. (2002) |
| Palm | $AGB = \exp\{-2.134 + 2.530 \times \ln(dbh)\}$ | Brown (1997) |
| Woody trees | | |
| Woody trees on Sumatra secondary forest | $AGB = 0.066dbh^{2.59}$ | Ketterings et al. (2001) |
| Allometric using specific ρ | $AGB = 0.11\ \rho dbh^{2,62}$ | Ketterings et al. (2001) |
| General allometric as comparison | $AGB = 0.118dbh^{2.53}$ | Brown (1997) |

Note: AGB: aboveground biomass (kg/tree); dbh: diameter at breast high (cm); d30: diameter at 30 cm from the ground (cm); pdbh: pseudodiameter; BA: basal area (cm$^2$); H: height (m); ρ: wood density (g cm$^{-3}$), (ρ is available on World Agroforestry Centre [http://db.worldagroforestry.org/wd])

## RESULTS AND DISCUSSION

### Cacao-based agroforestry in West Sumatra

West Sumatra is one of the provinces in Indonesia that develops small-scale cacao-based AFS known as *parak*. The cacao-based AFS patterns in West Sumatra varied greatly based on the composition, density, and intensity of management. Type of AFS in West Sumatra, according to Nair (1993) category, belongs to agrisilviculture practice, a form of land use that combines crops with woody trees. Referring to the typology of cacao plantation based on canopy cover trees (Rice and Greenberg 2000), the type of cacao development in West Sumatra varied from the unshaded cacao system (monoculture), mixed with one main productive shade trees such as rubber and coconut, to multi-strata cacao system. Multi-strata cacao system is a multi-shade AFS, composed of timber trees as the highest layer, productive shade trees such as fruit trees '*rambutan*' (*Nephelium lappaceum* L.), '*jengkol*' [*Archidendron pauciflorum* (Benth.) I.C.Nielsen] and'*petai*'(*Parkia speciosa* Hassk.) as the middle layer and cacao itself and other crops as the lower layer.

Pasaman and Padang Pariaman Districts are the two highest cacao producer regions in West Sumatra (West Sumatra BPS 2014). In Pasaman, the cacao plantation is dominated by a multi-strata AFS (CM) and cacao trees were grown under rubber trees (*H. brasiliensis*) (CR). In the early 1980s, farmers in Pasaman had developed rubber gardens. However, in the mid-1990s, rubber experienced a decrease in profitability and productivity so that farmers started planting cacao as the main crop under the remaining rubber trees. Farmers tended to choose cacao because it can be harvested within three to four years and is producing fruits throughout the year. In addition, the price of cacao beans tends to be stable in the market.

Cacao is a plant that naturally requires shade so that the farmers keep some of their former trees on their farm and they do not need to plant shade trees. In CM, farmers mixed woody trees as emergent layers such as '*surian*' (*Toona sureni* (Blume) Merr.) and '*bayua*' (*Pterospermum javanicum* Jungh.) with '*durian*' (*Durio zibethinus* Rumph. ex Murray), '*lansek*' (*Lansium Parasiticum* (Osbeck) Sahni & Bennet), '*pinang*' (*Areca catechu* L.), '*jengkol*' (*A. pauciflorum*) and 'candlenut' (*Aleurites moluccanus* (L.) Willd.) and cacao as main crop. To meet short-term income, they planted '*gardamunggu*' (*Amomum compactum* Sol. ex Matom) and chili (*Capsicum annuum* L.). In Padang-Pariaman District, the agricultural land was dominated by coconut. In line with Pasaman District, in the 1990s, farmers began to plant cacao under the coconut trees (CC), which also served as shade trees.

### Comparison of trees and saplings density and Stand Basal Area (SBA) on cacao-based AFS and monoculture

We estimated the aboveground C stocks of trees, palms, and bananas with published allometric equations based on dbh and d30. Aboveground C stocks were obtained from aboveground biomass through multiplication by 0.5. Table 2 shows a comparison of the averaged individual number of trees and saplings per hectare in each type of agroforestry. This table shows the number of cacao trees and saplings compared to non-cacao. CM is a type of agroforestry with the highest total number of trees and saplings, amounting to more than 1700 individuals per hectare. The highest number of saplings was found in CM. As what they called it *parak* (mixture farm), farmers did not do intense care and would just leave their farm filled with many kinds of planted and naturally growing trees, leaving their land with unproductive saplings that regenerate easily. The highest number of cacao tree per hectare was in monoculture with an average of 900 trees and 92 saplings per hectare. Although monoculture had the highest number of cacao trees per hectare, its Stand Basal Area (SBA) was the lowest, amounting only slightly less than 10 $m^2$ $ha^{-1}$. The tree densities of CM and monoculture were relatively within the range reported in Central Sulawesi (Rajab et al. 2016).

### Comparison of aboveground C-stock on cacao-based AFS and monoculture

Parameters used to measure the carbon dioxide binding level on a type of land-use were tree biomass (Mg $ha^{-1}$) and carbon biomass (MgC $ha^{-1}$). The carbon sequestration capacity provided by each pattern of cacao farming in West Sumatra is shown in Figure 2. The figure shows the capacity of cacao-based AFS and monoculture to sequester carbon in a hectare of land. Total aboveground C-Stock in biomass was six to ten times higher in the cacao-based AFS than in monoculture cacao. CC had the most carbon sequestered, amounting 103.42 MgC $ha^{-1}$, followed by CM with 99.23 MgC $ha^{-1}$. The least amount of carbon sequestered was in monoculture practice with only 10 MgC $ha^{-1}$.

Although CC had the lowest tree density among all AFS and lower SBA than CM, it contained higher aboveground C-Stock than CM. Therefore, the differences in aboveground C stocks between CC and CM were not as large as could have been expected from the tree densities and SBA alone. Besides tree density, the amount of carbon sequestered is affected by factors such as species, age and growth rate of trees. The coconut as main shade trees in cacao-based AFS in Padang Pariaman had been planted more than 30 years. They contributed a higher percentage of C-Stock than what cacao shade trees did in CM. In contrast to CM, most of the trees were at the same age as cacao because they were planted concurrently on

**Tabel 2**. Number of individuals and SBA of trees and saplings

| Type of land use | Number of individuals per hectare: Cacao Tree | Cacao Sapling | Cacao Total | Non-cacao Tree | Non-cacao Sapling | Non-cacao Total | Total | Stand Basal Area (SBA) ($m^2$ $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| CR | 538 | 125 | 663 | 454 | 96 | 550 | 1213 | 22.27 |
| CM | 433 | 225 | 658 | 675 | 450 | 1125 | 1783 | 34.42 |
| CC | 354 | 100 | 454 | 475 | 13 | 488 | 942 | 29.15 |
| M | 900 | 92 | 992 | 0 | 0 | 0 | 992 | 9.74 |

formerly unproductive rubber plantations. Only *durian* trees that were more than 25 years old. Another factor is the effect of farming maintenance. Our observation and interview suggested that farmers in Padang Pariaman, who developed CC and monoculture, allocated more labor and capital for maintenance and fertilization compared to farmers in Pasaman. Plant maintenance and fertilization will certainly affect the ability of plants in storing biomass. Among cacao-based AFS developed in West Sumatra, the cacao-rubber mixture (CR) had the lowest aboveground C-Stock of 61.89 MgC ha$^{-1}$. Rubber as the main shade tree is a productive tree species with low carbon binding ability, especially in rubber plantations with a short rotation. Nizami et al. (2014) reported that rubber plantations with a 25-year rotation were only able to bind carbon up to 65.91 MgC ha$^{-1}$.

Aboveground C-stocks consisted of carbon biomass of trees, saplings, seedlings, understorey plants, debris, and litter. Figures 3 and Table 3 show carbon biomass comparison based on carbon pool types. In terms of carbon pool type, CC had the most carbon sequestered in trees, amounting 101.77 MgC ha$^{-1}$, followed by CM with 94.69 MgC ha$^{-1}$. Most carbon sequestered in saplings occurred in CM (3.93 MgC ha$^{-1}$). The highest carbon biomass of seedlings, understorey, and litter was found in monoculture (1 and 1.71 MgC ha-$^{1}$, respectively, or more than 13% of its total carbon biomass). These data suggest that the biggest C-stock contributor for agroforestry practices was derived from tree vegetation types, ranging from 95 to 98%.

Figure 4 shows the percentage ratio of carbon biomass contributed by cacao to non-cacao trees and saplings. All carbon biomass of tress and saplings in monoculture was contributed by cacao. Regarding cacao-based AFS, carbon was dominantly sequestered by non-cacao trees with the percentage ranged from 86-96%. This percentage is relatively equal to that found in cacao agroforestry in Nigeria (Oke and Olatiilu 2011) but is higher than that of multi-strata agroforestry in Sulawesi with a non-cacao C-Stock percentage of only 81%.

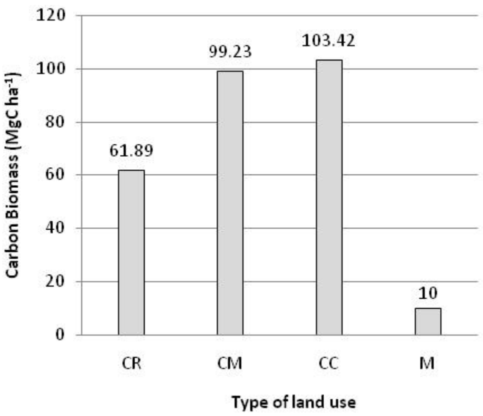


**Figure 2**. Total carbon biomass per hectare based on type of land use

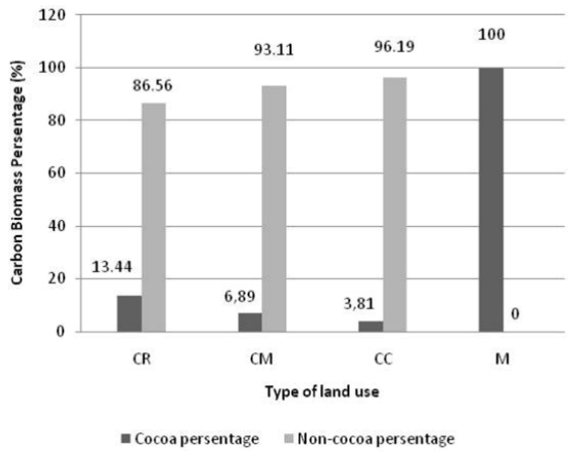


**Figure 4**. Cacao-Non-cacao carbon biomass persentage ratios

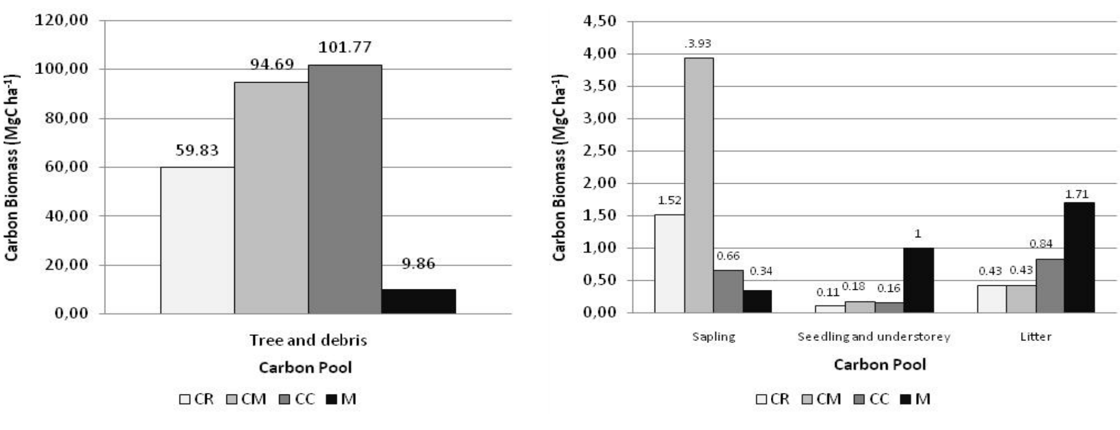


**Figure 3**. Carbon biomass per type of carbon pool

**Tabel 3**. Carbon biomass percentages per type of carbon pool

| Type of land use | Carbon Biomass Percentage (%) | | | |
|---|---|---|---|---|
| | Tree | Sapling | Seedling | Litter |
| CR | 96.68 | 2.46 | 0.18 | 0.69 |
| CM | 95.43 | 3.96 | 0.18 | 0.43 |
| CC | 98.40 | 0.64 | 0.15 | 0.81 |
| M | 75.83 | 3.38 | 7.66 | 13.13 |

The measured aboveground C-stocks in monoculture, cacao-rubber, cacao multi-strata, and cacao-coconut, were, respectively, 10, 62, 99 and 103 MgC ha$^{-1}$, and well within the range of values reported for cacao agroforests in other tropical regions. The present study results were compared with other published values (Table 4). The value of forests and trees in general in reducing carbon dioxide emission to the atmosphere is being recognized increasingly in the world over. Agroforestry systems are thus recognized to have the potential to regain some of the carbon lost to the atmosphere in the clearing of primary or secondary forests. Although neither it can come close to replacing the full amount of carbon that was present in the primary forest, agroforestry systems have the added benefit of providing valuable products and food to local people. To estimate how well agroforestry is in storing carbon, it is necessary to compare it with natural forests.

Several studies have assessed the biomass of natural primary and secondary tropical forests in Sumatra, Indonesia. Van Noordwijk et al. (2002) evaluated three remnants (secondary) forests in Sumber Jaya, Lampung with a mean estimated aboveground biomass of 390 Mg ha$^{-1}$ or containing 195 MgC ha$^{-1}$. In line with Van Noordwijk et al. (2002), Laumonier et al. (2010) have also assessed aboveground C-Stock land-scape of several dipterocarp forests of Sumatra, averaging 180.5 Mg ha$^{-1}$ (270-480) for trees with diameter above 10 cm. With an average of 88.18 MgC ha$^{-1}$, the cacao-based AFS in West Sumatra sequestered half as much as natural secondary forest did.

The main issue of development of cacao-based AFS in West Sumatra is that its short-term productivity is lower than monoculture. Farmers tended to plant their newly opened land with non-shade cacao systems. An alternative (or additional) pathway should be considered such as including them in environmental service reward schemes to provide incentives to cacao farmers for maintaining high C stocks in their farms. Agroforestry systems may have advantages over natural forest management in terms of C sequestration in situations where land and tree tenure are contentious issues related to the question of compensating for the opportunity cost of forest conservation. C offsets through 'agroforestation' in Indonesia seemed more likely to be applied than forest conservation because property rights over timber from planted trees would be easier to establish and enforce than property rights over timber from natural forests (Tomich et al. 2002). Therefore, agroforestry systems are recognized as an approved activity in the globally regulated carbon market.

Notwithstanding, just like most projects based on the rewards of environmental services, the stakeholders should anticipate the leakage phenomenon. Leakage is the possibility of rising greenhouse gas emissions in areas outside the project boundary due to afforestation (AR) or afforestation activities (Kollmuss 2008). Most cases of leakage are occurring when AR activities are performed; farmers can no longer cultivate their land with seasonal crops that provide short-term productivity for farmer's daily income. The farmers tend to open up new land by burying forests outside the project area for seasonal cultivation so that leakage occurs. Finally, whether cacao-based AFS can be a sink or a source of C depends on the land-use systems that they substitute. If they replace natural primary or secondary forests, they will accumulate comparatively lower biomass and C, but if they are planted on degraded or treeless lands, their C sequestration value is considerably increased.

**Tabel 4**. Carbon biomass percentages per type of carbon pool

| Source | Type | Location | Carbon Biomass (MgC ha$^{-1}$) |
|---|---|---|---|
| **This study** | Cacao-Rubber | West Sumatra | 61.89 |
| | Cacao Multi-strata | | 99.23 |
| | Cacao-Coconut | | 103.42 |
| | Cacao Monoculture | | 10 |
| Rajab et al. (2106) | Cacao Multistrata | Central Sulawesi | 47.60 |
| | Cacao-*Gliricidia* | | 14.00 |
| | Cacao Monoculture | | 7.70 |
| Sommariba et al. (2013) | Cacao Multistrata | Central America | 49.20 |
| Schroth et al. (2013) | Cabruca (traditional cacao agroforest) | Brazil | 82 |
| | Mature forest | | 183 |
| | Disturbed forest | | 102 |
| | Secondary forest | | 22 |
| Oke and Olatiilu (2011) | Cacao Multistrata | Nigeria | 96.01 |
| Schmitt-Harsh et al. (2012) | Coffee Multistrata | Guatemala | 73.18 |
| Van Noordwijk et al. (2002) | Remnant (secondary) forests | Lampung, Indonesia | 195 |
| Laumonier et al. (2010) | Dipterocarp forests | Sumatra | 180.5 |
| Istomo and Wibisono (2009) | (Mature) peatland forest | Indonesia | 126 |

Our data suggest that there are possible pathways for carbon-friendly intensification in cacao-based AFS. Total aboveground C-Stock in biomass was six to ten times higher in the cacao-based AFS than in monoculture cacao. The rotation time length in agroforestry systems plays a large role in the amount of carbon they can sequester. In multi-strata AFS, since rotation lengths varied within the system according to the species, complete clearing of land (which would increase the release of soil carbon) is less likely. Multi-strata cacao-based AFS are similar to the natural forest in the sense that a disproportional part of the total C stocks in the biomass is contained in the largest trees. The main principle should be the conservation of large trees while regularly thinning the self-shade canopies of overgrown cacao trees to make space for more cacao and other commercial trees and improve their light environment. A more detailed classification system would then be needed, along with more refined techniques for monitoring land use. Accordingly, this study could be a starting point for stakeholders in determining the definition of a baseline value for the C stocks of a cacao farm under best management practices and a reward for long-term C storage above this baseline. Besides government, chocolate companies, cacao beans trader and other stakeholders of the cacao value chain with interest in reducing their corporate environmental footprints and concerns about the environmental and economic sustainability of their suppliers and sourcing regions could be among potential investors in such incentive programs. In addition to carbon offsets payment scheme, cacao-based AFS such as those in Pasaman and Padang Pariaman Districts potentially obtain further opportunities in gaining additional incentives from enhancing water storage capacity services and biodiversity conservation. Therefore, further research on the prospect of carbon storage services and other fee mechanisms is needed in the presence of this cacao agroforest in West Sumatra.

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