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Carbon Stock of Agroforestry Systems at Adjacent Buffer Zone of Lore Lindu National Park, Central Sulawesi

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ABSTRACT

The potential of agrofrestry to sequestrate carbon varies depending on the natural quality of sites and management practices. Agroforestry is a climate change mitigation activities. The aim of study was to estimate the carbon stock of agroforestry system at adjacent buffer zone of Lore Lindu National Park (LLNP). Research was carried out in two types of agroforestry stands (simple and complex) adjacent LLNP buffer zone in Palolo Sub District, Sigi District, Central Sulawesi. Estimation of biomass of tree, herbs, litter, necromass and root was based on an allometric equation. The carbon storage in soil was estimated based on the carbon organic content and bulk density of soil in 30 cm of depth. The results of study showed that the total carbon stored in the simple agroforestry (125.97 MgC ha^{-1}) was significantly lower than in the complex agroforestry (209.39 MgC ha^{-1}). In addition, the aboveground carbon stock biomass (tree, herbaceous, necromass and litter) and belowground carbon stock (root and soil organic) in a simple agroforestry were 42.42 MgC ha^{-1} and 83.55 MgC ha^{-1}, respectively. Whereas, the aboveground carbon stock biomass and belowground carbon stock in the complex agroforestry were 98.46 MgC ha^{-1} and 110.93 MgC ha^{-1}, respectively. Based on the carbon stock estimation in six agroforestry plots in the buffer zones of Lore Lindu National Park, the complex agroforestry was likely to be more stable and more longer in storing carbon compared to the simple agroforestry.

Keywords: Agroforestry, biomass, carbon, climate change, Lore Lindu National Park

INTRODUCTION

Many agroforestry practices in Kalimantan (Nunukan), Sumatra (Jambi and Lampung) and Java (Wonosobo, Tasikmalaya and Ciamis) have been studied in case of the capability to capture carbon (van Nordjwick *et al*. 2002; Rahayu *et al*. 2005; Rusolono 2006). These practices have opportunity to be involved in carbon projects through the Clean Development Mechanisms as the implementation of carbon sequestration services under the Kyoto Protocol. Rahayu *et al*. (2005) stated that the ability of agroforestry to store carbon was about 37.7 Mg ha^{-1} at 1-10 years and 72.6 Mg ha^{-1} at 11-30 years.

Potential of agroforestry for carbon storage varies depending on the natural quality of the site and the management system of agroforestry (farming techniques, species composition, genetics characteristics and product utilization rate). *Populus deltoides* clone plantations over 5 years yielded almost twice as much as hybrids (Dowel *et al*. 2008) Generally, the carbon stored in the form of biomass is about 45-55%, both in the above and below ground. Therefore, research on carbon stocks in various patterns of agroforestry and in different sites should be studied, in order to obtain carbon stock estimation model, system monitoring and management schemes.

The objective of this study was to estimate the biomass and carbon stocks of aboveground (tree, herb, litter, and necromass) and belowground (root and soil) in the simple and complex agroforestry.

MATERIALS AND METHODS

Study Sites

The study was conducted on two types of agroforestry systems, namely simple and complex agroforestry at buffer zone area of the Lore Lindu National Park, Palolo Sub District, Sigi District, in Central Sulawesi. Site of the study is located at an altitude of 600-700 m above sea level. The complex agroforestry was defined based on number of plant species consisting of many species of trees, shrubs, bushes, and crops, while the simple agroforestry was only consist of woody tree species and cash crops (cocoa). The collection of biomass samples was conducted in April-July, 2009 in six agroforestry plots, three sample plots in each simple and complex agroforestry in three villages, namely: Rahmat, Kamarora and Tongoa villages. The sample of biomass then taken into the STORMA laboratory to be dryed in electrical oven and then the dry weight of biomass was estimated.

Data Collection Technique

Estimation of biomass of each tree, diameter at breast height (dbh) > 5 cm found in the sample plot was carried out by using the allometric equation. There were 35 trees of dominant cash crop tree species (cocoa) were cut to build the cocoa allometric equation. Firstly, the tree dimensions (dbh, total height, crown width, and free branch height) of all tree samples were measure and then harvested. All parts of the tree (trunks, branches, twigs, leaves, flowers and fruits) were collected and the total wet weight was weighed. Two biomass samples (± 200 g) of stems, branches, twigs, leaves, flowers and fruits were collected. The biomass samples of each part of the tree were taken to the STORMA laboratory to be dried in an electric oven at a temperature of 80^{o}C for 48 hours, and then be weighed to determine the dry weight of oven dry biomass. Based on the oven dry weight of each part of the tree, the total tree biomass was calculated. Furthermore, the allometric equation was built based on the diameter and total biomass of tree samples. The allometric equations obtained in this study were then used to estimate the total biomass of cocoa trees found in each sample plot.

Biomass of herbaceous was estimated with destructive methods, *i.e.* by harvesting all plants in sample plots (1 m × 1 m), then wet weight was weighed in the field, then a sample of 200 g for each plot was collected. Similar procedure were done for samples of dry stems/branches/twigs (necromass), diameter > 5 cm and length > 50 cm, in 5 m × 40 m plot. The length and diameter of necromass samples were measured every 5 m in length and the name of the tree species to determine the density was recorded. The litter sample was also collected from each square 0.5 m × 0.5 m plot. The total wet weight of litter was weighed in the field, then sample of 200 g was collected. All biomass samples were taken to the laboratory to be dried in an electric oven at a temperature of 80^{o}C for 48 hours, then weighed as dry weight. The oven dry biomass determination was based on Hairiah *et al.* (1999). Furthermore, the belowground carbon stocks were distributed in the tree roots and in the soil. The soil carbon was estimated by analyzing the soil organic carbon content (%) by Walkley-Black method of disturbed soil samples (± 30 cm of depth) and the soil bulk density (g cm^{-3}) of undisturbed soil samples. The carbon stored in the soil per hectare was calculated based on MacDicken (1997).

RESULTS AND DISCUSSION

Biomass

Aboveground biomass, especially tree biomass was estimated using allometric equations (Brown 1997) which was calibrated based on local conditions around the Lore Lindu National Park (Wardah 2008). While the cocoa tree biomass was estimated using allometric equations derived from the 35 cocoa tree samples at study site. The allometric equation obtained is $Y = 1.9114 * D^{1.1259}$. Total biomass was distributed on the trees, herbaceous, necromass, litter and roots, as presented in Table 1.

Table 1 shows that the total biomass in the simple agroforestry was likely to be lower than in the complex agroforestry. In general, the highest biomass was stored in the trees (73.09%), followed by 18.27% of biomass was stored in roots, 8.31% of the total biomass was stored on the ground (litter and necromass), and only 0.33% of total biomass was stored in herbaceous. There was a variation in tree biomass, especially in the simple agroforestry which was located very close to Lore Lindu National Park boundary. This was likely to be caused by the elder candle nut and cocoa tree (>15 years), the larger cocoa tree density (< 3 m) and irregular tree spacing. Whereas, the simple agroforestry was not located directly adjacent to the LLNP boundary (Rahmat and Tongoa villages) which had tree biomass lower than Kamarora village. This might be caused by tree spacing and the management history of agroforestry. The simple agroforestry in Kamarora village was developed from natural forest and the agroforestry, whereas in Rahmat and Tongoa villages were developed from the garden and the management was likely to be simpler than in Kamarora. The total tree biomass of simple agroforestry was close to the total aboveground and belowground biomass of the trees in 17 and 22 years old of *Tectona grandis* L.f. (89.3 Mg ha^{-1} and 98.8 Mg ha^{-1}, respectively) in Northen Thailand (Motoshi *et al*. 2005), even higher in the complex agroforestry.

Table 1. The composition of biomass (Mg ha^{-1}) in simple and complex agroforestry.

Agroforestry Type	Site	Tree	Herbaceous	Necromass	Litter	Root	Total
Simple Agroforestry (SAF)	1	80.48	0.53	0.11	3.67	20.12	104.92
	2	100.12	0.48	9.28	3.61	25.03	138.51
	3	67.38	0.53	1.31	3.93	16.84	90.00
Complex Agroforestry (CAF)	1	185.77	0.60	12.20	4.95	46.44	249.96
	2	236.63	0.51	39.67	5.30	59.16	341.28
	3	159.98	1.05	5.39	5.00	40.00	211.42
Mean		138.39	0.62	11.33	4.41	34.60	189.35
Percentage of total (%)		73.09	0.33	5.98	2.33	18.27	100.00

Tree biomass in simple agroforestry in study site had similarities with the biomass of trees in forest garden (56.7 - 99.8 Mg ha^{-1}) in Rompo village, the vicinity of the LLNP. The tree biomass in a complex agroforestry was similar to the biomass of trees in the elder forest garden and the old secondary forest. But the biomass of herbaceous in forest garden located in south-east part of LLNP was at the range of 1.3-2.2 Mg ha^{-1} (Wardah 2008). The differences between the biomass of herbaceous were likely to be caused by the differences in management/weed control. Palolo is located very close to Palu, so it is very easy to find herbicides compared to the Central Lore which tends to be more difficult and it is far from the market.

The very low of herbaceous biomass in this study could be caused by the chemical weed control and it prevented the competition of nutrients and water. Weeds were considered by farmers as a principal competitor of the cocoa plant, which might decrease the production of cocoa. Though several studies conducted on cocoa agroforestry around LLNP showed that chemical weed control did not give a significant yield increase of cocoa when compared to without doing spraying unless mechanical weed control (Clough 2009, personal communication).

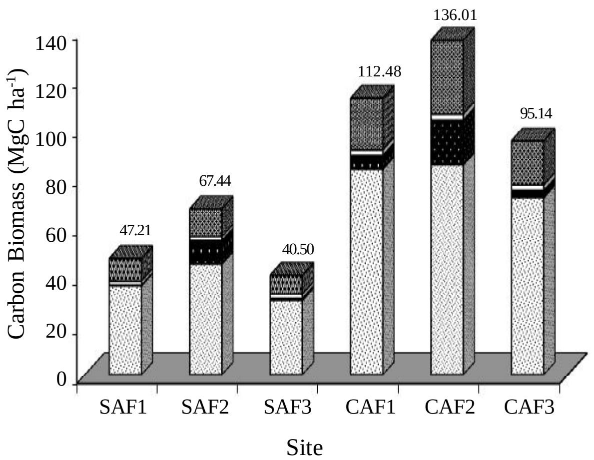

Figure 1. Comparison of carbon biomass stocks in a simple agroforestry (SAF) and complex agroforestry (CAF). ▪ = tree, ▪ = understorey, ▪ = necromass, ☐ = Litter, and ▪ = Root.

Biomass of trees in simple agroforestry was dominated by biomass of cocoa trees (± 70%) and it was only about 30% of biomass from the candle nut trees. While in the complex agroforestry it was a tendency on the contrary, where the biomass of tree was dominated by the candle nut, palm, ficus and others (> 75%) and biomass of cocoa trees was only about ≤ 25% of the total biomass of trees. The higher tree biomass of others (> 75%) than cocoa (≤ 25%) could be caused by government restrictions to cut down trees in the area LLNP, including in the forest garden that has long been managed before the LLNP area.

Carbon Biomass Storage in Agroforestry

Carbon stock in agroforestry might be distinguished based on the type of agroforestry (simple and complex). Variations of carbon stock based on the biomass sources are presented in Figure 1. Sources of carbon biomass stock distributed in agroforestry practices were derived from composed trees in the agroforestry, both the above and below layers of canopy trees. The average of carbon stocks of living trees was 37.30 MgC ha^{-1} with a range of 30.32-45.05 MgC ha^{-1} on simple agroforestry and the average of 80.05 MgC ha^{-1} with a range of 71.99-85.45 MgC ha^{-1} in a complex agroforestry. Carbon stocks in both agroforestry showed a significant difference. There was a similarity of carbon stock of living trees on simple agroforestry with stand carbon of cacao-agroforestry (>12 years old) in Nopu watershed catchment area, Central Sulawesi which reached 31.68 MgC ha^{-1} (Monde 2009).

Carbon stocks of tree in both agroforestrys as described above was relatively no different with the agroforestry practiced in Wonosobo and Ciamis which reached an average of 42.3 MgC ha^{-1} and 41.6-85.3 MgC ha^{-1}, respectively (Ginoga *et al*. 2004). But it was much higher when compared to the agroforestry practiced in Tasikmalaya which only stored carbon 19.5-25.1 Mg C ha^{-1}, which both were dominated by *Paraseriantes falcataria* (Rusolono 2006). Whereas in the eastern Panama, the managed forests might store an average of 335 Mg C ha^{-1}, traditional agroforestrys an average of 145 Mg C ha^{-1}, and pastures an average of 46 Mg C ha^{-1} including all vegetation-based C stocks and soil C to 40 cm depth (Kirby and Potvin 2007).

Besides carbon stored in forest trees (shade trees), there were also carbon stored in shaded trees (cocoa) which reached 63% and 21%, respectively of the total carbon in the tree of the simple and complex agroforestry. These data indicated that the cocoa tree is an important source of carbon in agroforestry practices in buffer zone of LLNP included in the study sites. In the simple agroforestry, carbon cocoa trees ranged 21.05-27.88 MgC ha^{-1} with an average of 23.47 MgC ha^{-1}. While in the complex agroforestry, carbon stock of cocoa tree tended to decrease, which ranges from 16.26 to 21.03 MgC ha^{-1} with an average of 18.67 MgC ha^{-1}. Smiley and Kroschel (2008) concluded that the highest aerial carbon level were attained at the fourth year in Napu (aerial cocoa–gliricidia = 20.74 MgC ha^{-1}) and at the fifth year in Palolo (aerial cocoa–gliricidia = 38.86 MgC ha^{-1}). After the fourth or fifth, however, there were reducing stocking density of gliricidia attributed to a loss of aerial C.

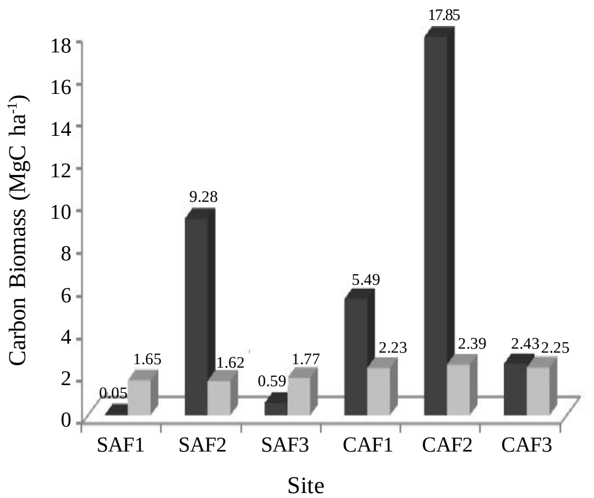

Figure 2. Carbon stocks in litter and necromass of simple agroforestry (SAF) and complex agroforestry (CAF). ■ = Necromass, dan ■ = Litter.

Carbon stored in herbaceous was relatively very small when compared with carbon from other sources. Carbon stored in herbaceous was only 0.23 MgC ha^{-1} and 0.32 MgC ha^{-1} for the simple and complex agroforestrys respectively, this amount was less than 1% of total aboveground carbon stocks. The very small amounts of carbon stored in herbaceous plants were due to the shorter life cycle (less than a year) as well as farmers looked at it as the major crop weeds of cocoa, so the herbaceous were always controlled by mechanical or chemical (herbicides) methods. Carbon stored in herbaceous plants in agroforestrys in this study site was likely to be lower compared to agroforestry in Rompo village, Central Lore Sub District, which ranged from 0.6-1.0 MgC ha^{-1} (Wardah 2008), but it was relatively no differences in agroforestry in Wonosobo and Ciamis, namely 0.3 MgC ha^{-1} for monoculture plantation and 0.2 MgC ha^{-1} for mixed farms (Rusolono 2006).

Carbon Storage on the Ground

Carbon stocks on the ground distributed in litter and necromass (dead tree) are very important in agroforestry practices. Carbon stored in litter and necromass might reach 5.00 -10.88 MgC ha^{-1} of the total biomass carbon (Figure 2).

The simple agroforestry had a lower litter carbon stocks on averaged 1.7 MgC ha-^{1} with a range of 1.62-1.77 MgC ha^{-1}, whereas in complex agroforestry might reach an average of 2.29 MgC ha^{-1} with a range of 2.23 to 2.39 MgC ha^{-1}. Higher carbon stocks in complex agroforestry than in the simple agroforestry were caused by higher density and number of tree species as well as the low frequency of maintenance and the age of agroforestry. The litter carbon stocks in agroforestrys, simple and complex, were relatively lower when it was compared with the results of research in monoculture plantation (2.8 MgC ha^{-1}) and mixed farms (2.8 MgC ha^{-1}) in Wonosobo and Ciamis (Rusolono 2006) and home garden in Lampung, which only stored carbon 2.0 MgC ha^{-1} (Roshetko *et al.* 1999).

Necromass or dead wood which consists of the remaining stump and the wood was relatively a little on simple agroforestry than on complex agroforestry. The existence of necromass was greatly vary from one agroforestry to another agroforestry, thus carbon of necromass tended to be unstable. The average of necromass carbon stocks was 3.31 MgC ha^{-1} with a range of 0.05 to 9.28 MgC ha^{-1}, which tend to be lower than the complex agroforestry with an average of 8.59 MgC ha^{-1} with a range of 2.43-17.85 MgC ha^{-1}. The high variation in necromass carbon of agroforestry can be caused by the historical development of agroforestry, where simple and complex agroforestry in the Kamarora Village (SAF2 and CAF2) located inside the buffer zone of Lore Lindu National Park, which is established from natural forests. Thus the high number of trees felled during the conversion of natural forest into agroforestry. While in simple agroforestry (SAF1 and SAF3) established from a garden, so that the dead trees less because the necromass just from branches and twigs of cash crop trees (cocoa).

Belowground Carbon Stock

Belowground carbon stored in roots and in soil organic carbon. The average of carbon stored in roots is 9.30 MgC ha^{-1} with a range of 7.58-11.26 MgC ha^{-1} in simple agroforestry, which is significantly lower than the average of carbon stored in complex agroforestry is 22.99 MgC ha^{-1} with a range of 18.00-30.09 MgC ha^{-1} (Figure 3). The higher carbon stock of roots in complex agroforestry might be caused by the stand structure and the high diversity of composition of tree species.

Furthermore, soil organic carbon was estimated up to 30 cm depth. Figure 3 shows the average of soil organic carbon in simple agroforestry are 83.55 MgC ha^{-1} with a range of 73.71-98.14 MgC ha^{-1}, which is relatively lower than in complex agroforestry (110.93 MgC ha^{-1}) with a range of 107.33-117.97 MgC ha^{-1}. The higher soil organic carbon in complex agroforestry might be contributed by the higher of litter and necromass carbon on the ground as a source of soil organic matter and microclimate condition support to high activity and population of soil organisms to decompose organic matter. Anas *et al.* (2005) concluded that population and activity of soil organisms in agroforestry, mainly with forest shade trees, tends to be no differences with natural forest.

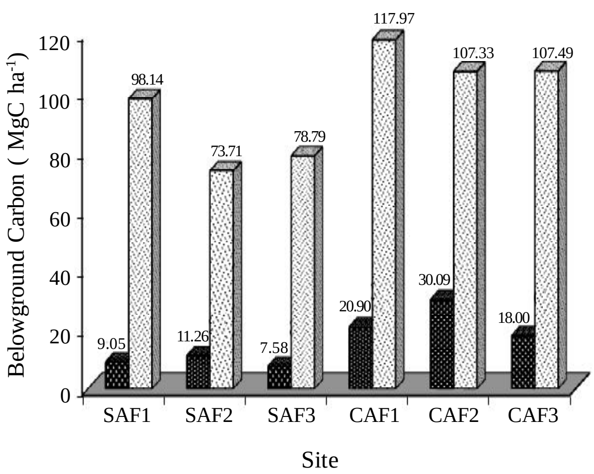

Figure 3. Belowground carbon (root and soil organic) in simple and complex agroforestries. ▩ = Root, and ▨ = Soil (30 cm depth).

The high soil organic carbon in the study site showed that the agroforestry management have been exist along time ago, soil organic carbon have been accumulated moderately high. The soil organic carbon in these agroforestrys are relatively higher than in home garden in Lampung (60.8 MgC ha^{-1}), monoculture plantation and agroforestry in Wonosobo and Ciamis (61.6 MgC ha^{-1} and 59.8 MgC ha^{-1}), and in 6 years old of *Gmelina arborea* plantation in Central India (Roshetko *et al.* 1999; Rusolonob 2006; Swamy *et al.* 2003). In contrast with the soil carbon stock in a 20-year-old teak (*Tectona grandis*) in Panama (225 MgC ha^{-1}) and in the 17-year-old stand of teak (211.4 MgC ha^{-1}, range: 153.2 to 251.8 MgC ha^{-1}) and 137.2 MgC ha^{-1} (range: 122.7 to 157.9 MgC ha^{-1}) in the 22-year-old stand of teak in Northen Thailand (Kraenzel *et al.* 2003; Motoshi *et al.* 2005).

Based on the carbon stocks estimation in agroforestrys, it could be expected, both simple and complex agroforestrys, to have a great potential carbon sequestration (more than 10 years) in accordance with the life cycle of tree crops planted. Therefore, the development and good management of agroforestry around and in the buffer zone of LLNP could be expected to may improve the welfare of the community around LLNP, enhancing the role of carbon sequestration that can decrease the rate of climate change and ultimately may have a positive impact on sustainability LLNP.

CONCLUSIONS

Total biomass in the simple agroforestry tends to be lower when compared with biomass in the complex agroforestry. In general, the highest biomass are stored in the trees (73.09%), 18.27% of biomass are stored in roots, 8.31% of the total biomass are stored on the ground (litter and necromass), and only 0.33% of total biomass stored in herbaceous.

Total carbon stored in the simple agroforestry (125.97 MgC ha^{-1}) is significantly lower than in the complex agroforestry (209.39 MgC ha-1). In addition, the aboveground carbon stock biomass (tree, herbaceous, necromass and litter) and belowground carbon stock (root and soil organic) in a simple agroforestry are 42.42 MgC ha^{-1} and 83.55 MgC ha^{-1}, respectively. Whereas, the aboveground carbon stock biomass and belowground carbon stock in the complex agroforestry are 98.46 MgC ha^{-1} and 110.93 MgC ha^{-1}, respectively.

The average of carbon stored in 30 cm of soil depth in simple agroforestry is 83.55 MgC ha^{-1} with a range of 73.71-98.14 MgC ha^{-1}, which is relatively lower than in complex agroforestry (110.93 MgC ha^{-1}) with a range of 107.33-117.97 MgC ha^{-1}.

Based on the carbon sequestration assessment in agroforestryry systems particularly adjecent buffer zone of Lore Lindu National Park, the complex agroforestry tends to be more stable and store carbon longer than the simple agroforestry that depends only on two types of crop trees (cocoa and candle nut).

Based on the research of carbon stocks in agroforestryry stands tend to vary, it can be suggested that: Carbon stocks in a simple agroforestry could be improved by enrichment planting with a commercial tree species.
Trading carbon through agroforestry practices require a more simple procedure, especially for estimating the carbon stored in agroforestry stands a very varied, covering the planted tree species and management techniques as well as agroforestry harvesting arrangement.

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