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Carbon sequestration of varieties coffee cropping systems in Tana Toraja district

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Abstract. Increase of CO₂ concentration in the atmosphere has increasingly become an issue as it causes global warming. Such an increase is partly brought about by change in land use and land cover. The research is aimed at identifying type of cropping system in smallholder coffee plantation in Tana Toraja district that provide the best CO₂ sequestration. The CO₂ sequestration were analysed by sampling the CO₂ content of plant biomass, plant residues, stems, soil organic matters, and undercover plants at varieties of coffee cropping system in Rante Deata village. The best CO₂ sequestration is the cropping system of coffee with Gliricidia (*Gliricidia sepium*) as shading plant (231.25 MT CO₂ ha⁻¹), followed by the intercrop of cocoa and coffee with Gliricidia (*Gliricidia sepium*) and suren (*Toona sureni*) as shading plant (198.55 MT CO₂ ha⁻¹). The least CO₂ sequestration is obtained at the cropping system of coffee – clove intercrop without shading plant (137.44 MT CO₂ ha⁻¹).

1. Introduction

Global warming is very much affected by the amount of greenhouse gas (GHG) in the atmosphere. The main GHG are carbon-dioxide (CO₂), methane (CH₄), and nitrous-oxide (N₂O). The contribution of these gasses to global warming is 89%, i.e. 66% by CO₂, 17% by CH₄, and 6% by N₂O. Other gasses contribute only 11% [1]. The increase in the concentration of CO₂ in the atmosphere is very prominent in 2017 which is reached 405.5 ppm, increased from 403.3 ppm in 2016 and 400.1 ppm in 2015 [2]. Current climate change is strongly influenced by global warming due to increased concentrations of GHGs in the atmosphere, especially CO₂ [3].

Carbon sequestration is the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere. Stored carbon or carbon stock is the amount of carbon that accumulates in carbon pools (carbon pools) within a certain period [4]. One reason for the increase in atmospheric CO₂ concentrations is the change in land cover from natural forests which are the highest carbon store to other land uses, burning of forests, draining of peatlands, and some land clearing practices that cause increased CO₂ emissions. Plants as absorber of CO₂ in the process of photosynthesis converts CO₂ into carbohydrates that are circulated to all parts of the plant and eventually is stored in leaves, stems, roots, flowers, and fruits. Thus, the measurement of carbon stored in living plants (biomass) indicates the amount of CO₂ in the atmosphere absorbed by plants. While the measurement of carbon stored dead plants (necro-mass) indicates the amount of CO₂ not released into atmosphere through combustion. Trees in forest and mixed gardens (agroforestry) store than annual crops [5].

The amount of carbon stored in vegetation varies, depending on the diversity and density of plants, soil types and crop management. Fertile soils store a large amount carbon, because fertile soils grow a



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big plant and store a large amount of organic content. Intercropping plantation with forest trees increases CO₂ absorption [6]. Hence, type of cropping system affects the amount of carbon stores in a particular land use and can be a mean of sequestering carbon in a particular land use.

The aim of this study is to access the amount of carbon stores in variety of coffee cropping system in Tarana Toraja. The finding is important to suggest a cropping system sequestering high carbon as a mean for mitigation of carbon emission.

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2. Materials and Methods

The research was conducted in Buntu Limbong Village, Tana Toraja District in August - October 2018. In this village there are three types of cropping system practiced in the coffee plantation, i.e; intercropping of Gamal-Coffee (system A), Clove-Pepper-Coffee (system B), and Cocoa-Surren-Gamal-Coffee (system C). Each system was sampled in three plots as replications that brings 9 plots all together. In each plot, sample was taken for soil analysis, wood density, plant biomass, litter, and understorey plants. The samples are analysed at the Soil Science Laboratory of the Faculty of Agriculture, Hasanuddin University.

Tree biomass was estimated using allometric models of Indonesian tropical tree species [7], i.e:

$$W = 0,11 \rho D^{2,62} \quad (1)$$

where : W = tree biomass (MT ha⁻¹)
 ρ = wood density (g cm³)
 D = Diameter of trees or nekromass up to 1.3 m height.

The biomass of coffee was estimated using equation [3], i.e.

$$W = 0,281 D^{2,06} \quad (2)$$

where : W = biomass (MT ha⁻¹)
 D = Diameter of tree or nekromass up to 1.3 m height

The biomass of the cocoa was estimated type using the equation [8], i.e:

$$W = 0,1208 D^{1,98} \quad (3)$$

where: W = biomass (MT ha⁻¹)
 D = Diameter of trees or nekromass up to 1.3 m height.

Biomass in under-storey and litter was estimated using equation [8], i.e:

$$W = (DW \text{ sampe} / WW \text{ sample}) \times WW \text{ total} \quad (4)$$

where: W = biomass (MT ha⁻¹)
 DW = dry weight (g)
 WW = wer weight (g)

The biomass in necromass was estimated using equation [8], i.e.:

$$W = \pi \rho H D^2/40 \quad (5)$$

where: W = biomass (MT ha^{-1})
 π = 3.14159265358979
 ρ = wood density (g cm^{-3})
 H = length or height of necromass (cm)
 D = diameter of necromass (cm)

Carbon contents of biomass is estimated by the conversion factor [9] as follows:

$$C = 0.5 \times W \quad (6)$$

where: C = Carbon (MT ha^{-1})

W = Biomass (MT ha^{-1})

Carbon content in the roots, it is estimated by the conversion factor [10] as follows:

$$C_{\text{root}} = 20\% \times C \text{ in above ground biomass} \quad (7)$$

Carbon content of the soil estimated from soil organic matter using the following equation [9]:

$$C = BD \times A \times D \times SOM \times 1 \text{ ha} \quad (8)$$

where: CC = carbon in soil (MT ha^{-1})
 BD = soil bulk density (g cm^{-3})
 A = area of sample plot (m^2)
 D = soil depth (m)
 C = soil organic matter (%)

The the amount of carbon emitted was estimated using the following equation [4], i.e.:

$$\Delta C = C_a - C_b \quad (9)$$

where: ΔC = Changes in carbon stored or emitted (MT ha^{-1})

C_a = Initial carbon stored (initial land cover before disturbance) (MT ha^{-1})

C_b = Carbon stored after disturbance (MT ha^{-1})

For each cropping system, plots of 20 x 20 meter were prepared as sampling unit, with three plots per cropping system. From these plots, biomass and carbon stored were calculated. For tree biomass calculation, the data take the tree diameters, tree heights, tree species, and tree specific gravities. Tree diameter at a height of 1.3 m from the ground surface (Diameter at Breast Height = DBH) were measured with a hagameter without destroying the plants. For under-storey biomass calculation, dry and wet weight of the plant were taken by damaging / cutting the plants at 1 x 1 m sub plot. For dry weight, 300 g wet weight biomass were oven dried at 60°C for 48 hours and weighed. For necro mass and litter biomass calculation, all litters in 1 m x 1 m sub plots were collected and weighed for wet and dry weight. For soil carbon content, soil samples were taken for soil organic matter, and bulk density analysis.

3. Results and Discussion

The amount of Carbon stored in varieties of trees is shown in table 1. The table shows that the largest stored carbon is in the composition of coffee and gliricidia species (cropping system A), followed by the mixture of coffee, gliricidia, cocoa and suren, (cropping system C), and the lowest stored carbon is coffee and cloves intercropping (cropping system B).

Table 1. Carbon stored in the trees of varieties of coffee cropping system in rante deata village

Cropping System	Types and population of cover					Biomass Weight (MT ha ⁻¹)	Carbon Content (MT ha ⁻¹)
	Coffee	Gliricidia	Cocoa	Clove	Suren		
A	69	14				69.12	34.56
B	73			10		40.02	20.01
C	71	6	4		3	61.68	30.84

In all cropping systems, the under-storey vegetation is dominated by torpedo grass (*Panicum repens*), creeping-oxeyes (*Wedelia* sp.), and goose-grass (*Eleusine indica*). whereas ferns (*Nephrolepis biserrata*), brazilian tea (*Stachytarpheta indica*) and spreading dayflower (*Commelina diffusa*) are found in small quantities. Estimated stored carbon in under-storey vegetation using equation in table 2 [8].

The pattern is similar to carbon stored in trees, where the highest is in Cropping system A, followed by cropping system C, then cropping system B.

Table 2. Carbon stored in under-storey vegetation in varieties coffee cropping system in rante deata

Cropping System	Types of vegetation	Biomass weight (MT/ha)	Carbon Content (MT/ha)
A	torpedo grass, creeping-oxeyes, brazilian tea, goose-grass, spreading dayflower.	2.52	1.26
B	torpedo grass, creeping-oxeyes, ferns, spreading dayflower	1.98	0.99
C	torpedo grass, goose-grass, ferns, brazilian tea, creeping-oxeyes	2.06	1.03

Carbon stored in necromass (in the form of dead trees) and litter of deciduous plants (in the form of leaves and twigs) is presented in table 3. The table shows that carbon stored in Cropping System A (coffee and gliricidia species) is the highest, followed by Cropping system C (coffee, gamal, cocoa, and suren), and the lowest is Cropping System B (coffee and clove). The pattern is similar to that for carbon stored in trees and under storey vegetation.

Table 3. Carbon stored in necromass and litter in varieties of coffee cropping system in rante deata

Cropping System	Necromass	Litter	Biomass Weight (MT/ha)	Carbon Content (MT/ha)
A	21.51	7.33	28.84	14.42
B	10.48	4.43	14.91	7.46
C	16.50	6.01	22.51	11.26

Stored carbon in rooting system is shown in table 4. The stored carbon is estimated 20% at 20% of stored carbon in above ground trees following estimation [10]. The table shows that the largest stored carbon in the rooting system is in Cropping System A (coffee and gliricidia species), followed by cropping system C, and the smallest is in Cropping System B (coffee and clove).

Table 4. Carbon stored in the rooting system of variety coffee cropping system in rante deata

Cropping System	Above Ground Carbon (MT/ha)	Carbon Stored in Rooting System (MT/ha)
A	34.56	6.91
B	20.01	4.00
C	30.84	6.17

Stored carbon in soil is shown in table 4. The stored carbon is calculated based on percentage of soil organic matter and soil bulk density following equation [11]. Cropping system, A has the highest stored carbon in the soil, followed by cropping system B and C.

Table 5. Carbon stored in the soil of varieties coffee cropping system in rante deata

Cropping System	BD	Sample Plot Size (m ²)	Soil Depth (m)	C-organic (%)	Stored Carbon in Soil (MT/ha)
A	1.37	400	0.20	2.14	5.86
B	1.35	400	0.20	1.85	4.99
C	1.42	400	0.20	1.69	4.80

The total carbon stored in each cropping system is the sum of carbon stored in trees, understory, necromass and litter, rooting system, as well as in the soil. Based on this, the total carbon stored in different cropping system is shown table 6. The table shows that the highest carbon stores is in cropping system A which is coffee crop with gliricidia as shading crop.

Table 6. Carbon Stored in varieties Coffee Cropping System in Rante Deata

Types of Cropping System	Sites of Carbon	Carbon (MT/ha)
Coffee and Gliricidia (Cropping System A)	Trees	34.56
	Under-storey	1.26
	Nekromass and litters	14.42
	Roots	6.91
	Soil	5.86
Total Carbon stored in Cropping System A		63.01
Coffee and Clove (Cropping System B)	Trees	20.01
	Under-storey	0.99
	Nekromass and litters	7.46
	Roots	4.00
	Soil	4.99
Total Carbon stored in Cropping System B		37.45
Coffee, Cocoa, Gliricidia, Suren (Cropping System C)	Trees	30.84
	Under-storey	1.03
	Nekromass and litters	11.26
	Roots	6.17
	Soil	4.80
Total Carbon stored in Cropping System C		54.10

This indicates that a coffee cropping system with tree as a shading crop that consist of a large wood content indicated by big diameter and tall height provide a large stored carbon. Therefore, a coffee cropping system stored the least carbon is cropping system B, which is intercropping of coffee and clove without shading crop. Intercropping of coffee and cocoa with gliricidia and suren as shading crop (cropping system C) stores more carbon than cropping system B, but less than cropping system A.

Based on amount of carbon stored in each cropping system, amount of gas CO₂ that has been sequestered can be calculated by multiplying stored carbon to ratio of molecular weight of carbon dioxide and carbon elements, which is 44/12 or 3.67. Based on this, the amount of CO₂ sequesters by coffee plantation with gliricidia as shading crop is 3.67 x 63.01 tons C / ha = 231.25 tons CO₂ / ha. A coffee plant intercropped with clove without shading crop sequesters the least CO₂ which is 3.67 x 37.45 tons C / ha = 137.44 tons of CO₂ / ha, while intercropping of coffee and cocoa with gliricidia and suren as shading crop sequesters CO₂ in the amount of 3.67 x 54.10 tons C / ha = 198.55 tons of CO₂ / ha.

4. Conclusions

Intercropping of coffee and gliricidia in the coffee cropping system give the highest carbon stored, i.e. 63.01 MT/ha. Such cropping system has sequestered carbon in the amount of 231.25. One of the distinct characters of this cropping system to others is use of shading crop with high wood content.

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