Carbon stock analysis of some cocoa planting systems in climate change mitigation efforts in East Luwu Regency

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Abstract. Global warming is very closely related to carbon stored in an ecosystem. This research aimed to determine the amount of carbon storage in cocoa plantations in East Luwu Regency. The research was carried out in cacao plantation in three districts namely Burau, Wotu and Mangkutana. Measurement of carbon storage was conducted using the allometric formula on an observation plot of 200 m². Six sampling points were selected consisted of four location with shading trees planted in multistraata agroforestry planting system and two locations with a monoculture planting system. The results of measurements on cocoa plants show that carbon storage increased with the variety of plant species that exist in the cocoa farm. The size of the carbon stocks depends on the planting system. Cacao plantation with multistrata shades system showed carbon absorption of 148.92 tons/Ha that was greater than the amount of carbon absorption in cocoa plantation with monoculture shades system of 50.24 tons/Ha. The level of carbon uptake in East Luwu Regency is 33.19 tons C/Ha. The amount of carbon emissions absorbed is 57.46 t/Ha. CO₂ content with the composition of existing land cover in East Luwu Regency is 121.81 tons CO₂/Ha.

1. Introduction
Global warming is one of the important environmental issues which is currently a concern of many parties. The consequences of global warming include an increase in the average temperature of the earth’s marine and terrestrial atmosphere caused by industrial activities and the reduction in land cover, especially forests due to the rate of land degradation. The Fourth Assessment of IPCC report in 2007 also mentioned a 70% increase in greenhouse gas (GHG) concentrations from 1974-2005. About 20% of the increase in GHGs is caused by the release of CO₂ that have been stored for hundreds to thousands of years as aboveground biomass and in peat soils [1]. Apart from industrial progress, the main cause is because many forests on earth are damaged and no longer able to store carbon. One of the reasons for the increase in CO₂ gas emissions is the loss of biomass due to the deforestation [2,3].

One factor that can reduce the accumulation of CO₂ in the atmosphere is absorption by vegetation. The development of plantation forests is one of the forestry businesses that is seen as activities that can reduce emissions by increasing carbon stocks. Carbon stock is the carbon content stored, both above ground such as plant biomass or in the soil such as soil organic matter. When trees are cut in a crop field, it would cause a breakdown of carbon that had been stored in plant biomass and then decomposed into the air. Most elements of C that decompose to the air are usually
bound to O\textsubscript{2} and become CO\textsubscript{2}. This change in carbon form then becomes the basis for calculating emissions. When an empty field is planted with plants, there will be a process of binding the element C from the air back into plant biomass gradually as the plant grows large (sequestration). Therefore, the size of the volume of the building blocks of the land can be a measure of the amount of carbon stored as biomass (carbon stocks) [4]. Measurement of carbon stocks needs to be done in order to obtain carbon stock data stored in the atmosphere so that emissions can be calculated to be released into the atmosphere when there is a change in land cover.

One of the efforts to mitigate climate change is by reducing excessive land use such as deforestation as the forests themselves function as carbon storage. Other efforts can be made by adding, strengthening or expanding earth systems that function as carbon sinks, so that CO\textsubscript{2} and GHG emissions released in the air can be captured, absorbed and stored again in trees. When trees are cut down, forests are cut down, the carbon stored will be released again as exhaust emissions that pollute the air and re-accumulate in the atmosphere [5].

Cacao is one of the C3 plantations which means it requires shade for its growth. Cocoa is generally managed with an agroforestry system. Agroforestry is an appropriate land use system to support sustainable agriculture. The implementation of the Agroforestry system is an appropriate land use system to support sustainable agriculture. Agroforestry in cocoa plants functions as a conservation of the environment so that cocoa plantations have the dual function of supporting sustainable agriculture and as a conservation [6].

Cocoa as one of the widely developed plantation commodities in Indonesia has a strategic position in efforts to increase carbon sequestration to reduce the rate of global warming. The process of accumulating C in the body of living plants is called the sequestration process [7]. Therefore, by measuring the amount of carbon stored in plants that are still living on a land, the amount of CO\textsubscript{2} in the atmosphere absorbed by plants can be measured. Measurements of C that are still stored in dead plant parts can describe CO\textsubscript{2} that is not released into the air through combustion.

Biomass measurements performed on plants generally use the non-destructive method. The non-destructive method is a method of measuring CO\textsubscript{2} absorption without destroying the plant parts. Measurement of plant biomass can be done using allometric equations. The allometric equations developed by previous researchers are directly proportional to the diameter of the plant, the density of wood and plant height [8].

As a woody plant, cocoa can absorb CO\textsubscript{2} from the air and stored in the form of carbon (C) in its body (biomass). The process of CO\textsubscript{2} absorption also influences the rate of plant photosynthesis as the main ingredient in the decomposition of carbon in the body of the plant, especially cocoa. Plants or trees in the forest and estate crops function as carbon storage or deposition (carbon sink or carbon sink) [9]. The amount of carbon and biomass of the tree varies based on the part of the plant being measured, growth stage, plant level and environmental conditions.

The carbon content and biomass of understorey is influenced by the types of constituent plants [10]. A layer of litter is all dead organic material that is above the soil surface. Some of these organic materials can still be recognized or are still slightly decomposed [11]. Soil microorganisms play a role in the decomposition of soil organic matter and as the final product of this process is the release of CO\textsubscript{2} [12]. Therefore measuring the amount of carbon in biomass in a field can describe the amount of CO\textsubscript{2} in the atmosphere absorbed by plants, and measuring carbon in the part of plants that have died (necromass) can describe CO\textsubscript{2} that is not released into the air through combustion. This research is expected to be able to find out the estimated carbon stored in a number of cropping systems that have been implemented in East Luwu Regency and to study the differences in carbon storage potential in each cocoa planting system in East Luwu Regency.

2. Methodology
The location of the study was the community cocoa plantations in East Luwu districts (Burau, Wotu and Mangkutana Districts). The soil analysis was conducted at the Soil Science Laboratory, Faculty
of Agriculture, Universitas Hasanuddin. This research was conducted for 6 months starting from January to June 2019.

2.1. Data analysis
There are three categories of cocoa plantations that served as research indicators, namely (K0) cocoa plantations as a control (without rare shades/shades), (K1) cocoa plantations with monoculture shades and (K2) cocoa plantations with generally diverse shade trees or multistrata shades. The measurement of dry weight was distinguished from the main plant biomass (cocoa), shade plant biomass or other trees. Necromass and understory biomass were also measured.

Data analysis was conducted on the data of identification of vegetation types of land cover both trees and understory. The potential for carbon storage of plants and soil organic C content were analysed. To estimate tree biomass allometric models of Indonesian tropical tree species [13] were used as shown in table 1.

| Tree     | P    | Allometric Formula | Source |
|----------|------|--------------------|--------|
| Cacao    |      | BK = 0.1208 D^{1.98} | [14]   |
| Gamal    | 0.74 | BK = 0.11 ρ D^{2.62} | [15]   |
| Clove    | 1.20 | BK = 0.11 ρ D^{2.62} | [15]   |
| Coconut  | 0.66 | BK = 0.11 ρ D^{2.62} | [15]   |
| Banana   |      | BK = 0.030 D^{5.13} | [16]   |

BK = Dry weight (kg / tree) D = tree diameter or dbh (1.3 m) ρ = wood specific gravity (g / cm$^3$)

In estimating the biomass of necromass in cocoa plants use equation [17]:

$$W = \pi \rho H D^2/40$$

where :

W = biomass (t/Ha)

$\pi = 3.14159265358979$

$\rho = $ wood specific gravity (g/cm$^3$)

H = length/height necromass (cm)

D = necromass diameter (cm)

The formula for containing the C (carbon) content around the roots, is estimated by the conversion factor [18] as follows:

$$C_{\text{root}} = 20\% \times C \text{ above ground tree biomass}$$

The formula for estimating soil C (carbon) content uses equation [19] as follows:

$$KC = B \times A \times D \times C \times 1 \text{ ha}$$

where :

KC = carbon content (t/ha)

B = soil specific gravity (g/cm$^3$)

A = sample plot size (m$^2$)

D = soil depth (m)

C = carbon content (C% organic soil)

The equation for estimating carbon emission is used by the equation [20] as follows:

$$\Delta C = Ca - Cb$$

Where:

$\Delta C = $ Changes in stored carbon or emissions (t/ha)

Ca = Initial stored carbon (initial closure before disturbed) (t/ha)

Cb = Final stored carbon (closure after disturbance) (t/ha)
2.2. Implementation stage
The activity began with the creation of sample plots and continues with data collection of trees, undergrowth, necromass (litter), and soil. The sample plot was made with a size of 40 m x 5 m. Observation plots were measured using a meter and marked with pegs at each angle then wrapped around a raffia rope as a sample plot boundary.

To obtain the estimation data of the tree biomass, some parameter were measured including the diameter of the tree, tree height, tree species, and tree specific gravity. Measurement was made on all tree species in the sample plot. Diameter of the tree was measured in situ, without destroying plants or trees, at a height of 1.3 m from the ground surface (Diameter at chest height or Diameter at breast height = DBH). The tree height was measured using a hagameter.

For estimating the biomass of understorey and necromass plants, wet and dry weight of the plant were measured. Sampling was done by making a plot with a size of 1 m x 1 m and destroying / cutting all the plants that are in the sample plot. Subsequently, all types of plants that in the sample plot were recorded and placed in an envelope and labeled for each sample plot for weighing of the plant wet weight. For the dry weight of plant biomass, 300 g was taken as a sub sample. Whole plants were taken for sub sample if the plant biomass is <300 g. Sub sample then dried at 80 °C for 48 hours or until it reaches a constant dry weight. For soil C estimation data, soil sampling was performed on each sample plot and soil analysis was carried out for soil texture, soil density, pH, CEC, and organic C.

3. Results and discussion
3.1. Tree vegetation
The results show that East Luwu Regency was dominated with cocoa (as the main crop), gamal (Gliricidia sepium), coconut and banana. Table 2 presents the results of the calculation of average carbon stored in a 40 m x 5 m sample plot. Plant density information of plants except for cocoa is required in the calculation of biomass. The specific density of gamal and coconut was 0.74 g/cm³ and 0.66 g/cm³, respectively [21].

| Locations                 | Cropping Patterns | Cacao | Gamal | Coconut | Banana | W (ton/ha) | C (ton/ha) |
|---------------------------|-------------------|-------|-------|---------|--------|------------|------------|
| District Burau Village    |                   |       |       |         |        |            |            |
| Jalalja                   | K2                | 15    | -     | 5       | 2      | 26.56      | 13.28      |
| District Burau Village    |                   |       |       |         |        |            |            |
| Village Kalaena           | K2                | 12    | 5     | 2       | 2      | 15.07      | 7.535      |
| District Wotu Village     |                   |       |       |         |        |            |            |
| Tarengge                  | K1                | 15    | 6     | -       | -      | 9.19       | 4.595      |
| District Wotu Village     |                   |       |       |         |        |            |            |
| Cendana Hijau             | K2                | 15    | 3     | 4       | 2      | 50.75      | 25.375     |
| District Mangkutana       |                   |       |       |         |        |            |            |
| Village Balaikembang      | K1                | 16    | 8     | -       | -      | 20.81      | 10.405     |
| District Mangkutana       |                   |       |       |         |        |            |            |
| Village Wonorejo Timur    | K2                | 16    | 2     | 2       | 1      | 11.32      | 5.66       |

Table 2 shows that the largest stored carbon in East Luwu Regency of 25,375 tons / Ha was found in the K2 planting pattern in Wotu District, Cendana Hijau Village with the composition of
cocoa, gamal, coconut and banana plants. The lowest stored carbon of 4,595 tons was found in K1 planting pattern in Wotu District, Tarengge Village with the composition of cocoa and gamal plants.

3.2. The vegetation of the lower plants
The vegetation of the lower strata plants was dominated by kentangan (*Borreria latifolia*), krinyuh (*Chromolaena odorata*), harendong (*Clidemia hirta*), babandotan (*Ageratum conyzoides*), grass (*Cyperus rotundus*), jambean (*Selaria plicata*) and mikania (*Mikania micrantha*). Table 3 presents the stored carbon data of the understory plant in a cocoa plantation in East Luwu Regency. Table 3 shows that carbon stored in the understorey is dominated by mikania, species and babandotan.

### Table 3. Carbon stored in plant vegetation under cocoa plantation in East Luwu

| Locations                | Cropping Patterns | The vegetation of the lower plants                  | W (ton/ha) | C (ton/ha) |
|--------------------------|-------------------|-----------------------------------------------------|------------|------------|
| District Burau Village Jalajja | K2                | Kentangan, harendong, mikania dan babandotan        | 9.9        | 4.95       |
| District Burau Village Kalaena | K2                | Kentangan, mikania, jambean, krinyuh                | 14.1       | 7.05       |
| District Wotu Village Tarengge | K1                | Krinyuh, rumput teki, Jambean, babandotan, dan mikania | 6.4        | 3.2        |
| District Wotu Village Cendana Hijau | K2            | Harendong, mikania, jambean dan krinyuh              | 10.4       | 5.2        |
| District Mangkutana Village Balaikembang | K2        | Kentangan, jambean dan krinyuh                      | 8          | 4          |

### Table 4. Carbon stored in necromass and litter of cocoa plantations in East Luwu

| Locations                | Cropping Patterns | Nekromassa | Litter | W (ton/ha) | C (ton/ha) |
|--------------------------|-------------------|------------|--------|------------|------------|
| District Burau Village Jalajja | K2                | 58.1       | 15.1   | 73.2       | 36.6       |
| District Burau Village Kalaena | K2                | 10.6       | 10.6   | 21         | 5.3        |
| District Wotu Village Tarengge | K1                | 11.5       | 11.5   | 23         | 5.75       |
| District Wotu Village Cendana Hijau | K2            | 8.9        | 8.9    | 17.8       | 4.45       |
| District Mangkutana Village Balaikembang | K1        | 7.2        | 7.2    | 14.4       | 3.6        |
| District Mangkutana Village Wonorejo Timur | K2            | 11.8       | 11.8   | 23.6       | 5.9        |

3.3. Nekromasa and litter
Nekromass (litter) is a dead tree both upright and uprooted. Litter is part of a plant that has fallen in the form of leaves and twigs that are on the surface of the ground. In table 4, carbon data stored on necromasses and litter in a cocoa plantation in East Luwu Regency are shown. Table 4 shows that in East Luwu Regency, the most carbon stock found in the K2 planting pattern in Burau District, Jalajja
Village (C = 36.6 ton/Ha) while the lowest carbon absorption value was in the K1 planting pattern in Mangkutana District, Balai Kembang Village (3.6 ton/Ha).

3.4. Roots
Stored carbon for rooting areas is estimated at 20% of stored carbon in tree stands above the soil surface [17] as in table 5. Table 5 shows that the largest stored carbon in the rooting area lied in the K2 cropping pattern and followed by the K1 cropping pattern.

| Locations                  | Cropping Patterns | Carbon Stored in Above ground Biomass | Carbon Stored in Underground Biomass |
|----------------------------|-------------------|--------------------------------------|--------------------------------------|
| District Burau Village Jalajja | K2                | 13.28                                | 2.656                                |
| District Burau Village Kalaena | K2                | 7.54                                 | 1.507                                |
| District Wotu Village Tarengge | K1                | 4.60                                 | 0.919                                |
| District Wotu Village Cendana Hijau | K2                | 25.38                                | 5.075                                |
| District Mangkutana Village Balaikembang | K1                | 10.41                                | 2.081                                |
| District Mangkutana Village Wonorejo Timur | K2                | 5.66                                 | 1.132                                |

| Locations                  | Cropping Patterns | Texture (%) | pH | C-Organik (%) | KTK (cmol(+)/kg) |
|----------------------------|-------------------|-------------|-----|---------------|-----------------|
| District Burau Village Jalajja | K2                | 6           | 51  | 42           | 5.6             | 2.32           | 1.80 |
| District Burau Village Kalaena | K2                | 2           | 44  | 54           | 5.4             | 1.33           | 1.08 |
| District Wotu Village Tarengge | K1                | 64          | 23  | 13           | 4.9             | 1.29           | 0.32 |
| District Wotu Village Cendana Hijau | K2                | 56          | 24  | 4.9          | 4.9             | 1.41           | 9.51 |
| District Mangkutana Village Balaikembang | K1                | 59          | 23  | 4.9          | 5.3             | 1.4            | 0.55 |
| District Mangkutana Village Wonorejo Timur | K2                | 86          | 5   | 5.3          | 5.1             | 1.8            | 13.40 |
3.5. *Land*

The results of the soil analysis presented in table 6 show that the soil in the research sites dominated with coarse texture, average pH of 5.2, C-Organic of 59% and CEC of 4.44. The results of the soil carbon content calculation of based on equation [18] are presented in table 7. Table 7 shows that the carbon content stored in the soil in cocoa plantations in East Luwu Regency varied between planting system. Cocoa plantation with shade trees managed in multistrata agroforestry system showed higher carbon stock than the plantation with monoculture shade trees. Highest carbon stock was found in K2 planting system in Burau District, Jalajja Village (11.97 ton/ha), while the lowest was in K1 in Mangkutana District, Balai Kembang Village (5.2 ton/ha).

**Table 7. Soil analysis of cocoa plantation in the research sites**

| Locations                  | Cropping Patterns | DB | Area of sample Plot (m²) | Soil Depth (m) | C Organic (%) | C Soil (t/ha) |
|----------------------------|-------------------|----|--------------------------|----------------|---------------|---------------|
| District Burau Village     |                   |    |                          |                |               |               |
| Jalajja                    | K2                | 1.29| 200                      | 0.2            | 2.3           | 11.97         |
| District Burau Village     |                   |    |                          |                |               |               |
| Kalaena                    | K2                | 1.35| 200                      | 0.2            | 1.3           | 7.18          |
| District Wotu Village      |                   |    |                          |                |               |               |
| Tarengge                   | K1                | 0.41| 200                      | 0.2            | 1.3           | 6.04          |
| District Wotu Village      |                   |    |                          |                |               |               |
| Cendana Hijau              | K2                | 11.24| 200                      | 0.2            | 1.4           | 7.21          |
| District Mangkutana Village|                   |    |                          |                |               |               |
| Balaikembang              | K1                | 0.65| 200                      | 0.2            | 1.4           | 5.21          |
| District Mangkutana Village|                   |    |                          |                |               |               |
| Village Wonorejo Timur     | K2                | 12.41| 200                      | 0.2            | 1.8           | 9.58          |

**Table 8. Carbon stored in various patterns of composition of cocoa plantation in East Luwu**

| Locations                  | Cropping Patterns | Carbon Sequestration (t/ha) | Total C (ton/ha) |
|----------------------------|-------------------|-----------------------------|-----------------|
| District Burau Village     |                   |                            |                 |
| Jalajja                    | K2                | 13.28                       | 4.95            | 11.97          | 40.28         |
| District Burau Village     |                   | 7.54                        | 7.05            | 10.58          | 33.85         |
| Kalaena                    | K2                | 4.60                        | 3.20            | 4.80           | 19.55         |
| District Wotu Village      |                   | 25.38                       | 4.30            | 6.45           | 48.42         |
| Tarengge                   | K2                | 10.41                       | 5.20            | 7.80           | 30.69         |
| District Wotu Village      |                   | 5.66                        | 4.00            | 6.00           | 26.37         |

| District Cendana Hijau     |                   |                            |                 |
| Village                   | K2                |                            |                 |
| District Mangkutana Village|                   |                            |                 |
| Balaikembang              | K1                |                            |                 |
| District Mangkutana Village|                   |                            |                 |
| Village Wonorejo Timur     | K2                |                            |                 |

Average 33.19

C1: Carbon Absorption of Cocoa + Shade Trees; C2: Uptake Carbon Absorption; C3: Nekromasa + Litter Carbon Uptake; C4: Root Carbon Uptake; C5: Carbon Absorption in the Soil.
3.6. Stored carbon
The results of the stored carbon calculation indicate that variation in the composition of plant species in an area will result in variations in the amount of carbon stored in a planting area. Details of the carbon stored in a various plant species compositions managed in different cropping patterns are presented in table 8.

Table 8 shows that the composition of cocoa plantations in the K2 absorbed the most carbon. This illustrates that the agroforestry cocoa cultivation pattern is suitable to support sustainable agriculture. Aside from making tangible and diverse contributions, agroforestry system also functions as a conservation of the environment and social conditions so as to guarantee a wider economy and higher food security. Thus, cocoa plantations have the potential to play a dual role, namely as producers of economic value commodities and as environmental conservation in terms of carbon sequestration.

3.7. Carbon emissions
Carbon emissions from a land cover changes from plantations to plantations based on historical land use. The carbon stored in plantation forests in Sulawesi [19] is 92.65 ton/Ha. Thus the carbon emissions that occur in East Luwu Regency was calculated as follow:

\[ \Delta CA = 92.65 - 33.19 = 59.46 \text{ t/Ha} \]

The results of the calculation above means that the quite dense composition of land cover resulted in the lowest carbon emissions of 59.46 t/Ha in East Luwu Regency.

3.8. Content of CO₂
The amount of carbon dioxide absorbed in the sample plot area was calculated by multiplying the amount of carbon stored in the sample plot by the ratio of molecular weights of carbon dioxide and carbon elements, which is 44/12 or 3.67 [21]. The amount of CO₂ content in the composition of land cover types in East Luwu Regency is 3.67 x 33.19 tons C/Ha = 121.81 tons CO₂/Ha.

4. Conclusions
Based on the results of the calculation of the carbon stored in a cocoa plantation in South Sulawesi it can be concluded that:
1. The level of carbon uptake in East Luwu Regency is 33.19 tons C/Ha. The amount of carbon emissions absorbed is 57.46 t/Ha. In terms of CO₂ content in the composition of existing land cover in East Luwu Regency is 121.81 tons CO₂/Ha.
2. The right strategy in developing cocoa plantations is by applying the multistrata agroforestry planting system.

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