Carbon stock analysis of some cocoa planting systems in South Sulawesi

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Abstract. In an effort to control carbon emissions in the air, steps taken are improving forest vegetation and protecting natural forest vegetation as the biggest absorber of carbon gas emissions. Cocoa as the largest plantation crop in Indonesia is expected to be able to absorb CO₂ gas emissions in the air due to its ability to absorb carbon. A carbon analysis study was carried out on cacao plantation to determine the level of carbon uptake in each cropping system in South Sulawesi. Hence, the results of the analysis can be a reference in climate change mitigation efforts. Three regencies, each with 3 districts were selected as study locations, namely East Luwu Regency (Burau, Wotu and Mumpangana Districts), Pinrang Regency (Patampanua, Batulappa and Lembang Districts), and Bantaeng Regency (Gantarangkeke, Tompobulu, and Eremerasa Districts). Carbon stored measurements was conducted using allometric formula. Measurements were carried out on 200 m² observation plot. Results show that carbon sequestration levels were 33.19 tons C/ha, 25.52 tons C/ha, 32.07 tons C/ha in East Luwu, Pinrang and Bantaeng regencies, respectively. The amount of carbon emissions absorbed in East Luwu Regency was 57.46 t/ha, Pinrang Regency 67.12 t/ha, and Bantaeng Regency 60.07 t/ha. The CO₂ content based on the composition of land cover in East Luwu Regency was 121.81 tons CO₂/ha, Pinrang Regency 93.69 tons CO₂/ha, and Bantaeng Regency 117.70 tons CO₂/ha.

1. Introduction

Climate changes and the current issue of global warming are triggering the necessity for information on carbon at present time. Carbon is a natural cycle where carbon in the atmosphere is absorbed by vegetation and then released back into the atmosphere. Climate change occurs due to changes in atmospheric composition, mainly due to an increase in greenhouse gas (GHG) concentrations. The Fourth Assessment of the IPCC in 2007 also mentioned a 70% increase in greenhouse gas concentrations from 1974-2005. About 20% of the increase in GHGs is caused by the release of CO₂ that has been stored for hundreds to thousands of years as aboveground biomass and in peat soils [1].

Apart from industrial progress, the main cause of increased GHGs is because many forests on earth are damaged [2] 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 logging from the plantation area. One factor that can reduce the accumulation of CO₂ in the atmosphere is absorption by vegetation.

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 [3]. The process of
accumulation of carbon in the body of a living plant is called the sequestration process [4]. Therefore, by measuring the amount of carbon stored in a living plants on a specified land the amount of CO\(_2\) in the atmosphere absorbed by plants can be measured. In addition, measurement of carbon stored in dead parts of the plant can describe CO\(_2\) that is not released into the air through combustion.

One of the efforts made to help reduce CO\(_2\) emissions is to maintain the plantation ecosystem [5]. Plants have a role in mitigating climate change, which can reduce the amount of emissions and/or increase CO\(_2\) absorption and carbon sequestration. As a woody plant, cocoa can absorb CO\(_2\) from the air and stored in the form of carbon (C) in its body (biomass). The process of CO\(_2\) absorption also influences the plant photosynthesis rate as CO\(_2\) is the main ingredient in the decomposition of carbon in the body of the plant, especially cocoa. Thus measuring the amount of C levels stored in the body of living plants (biomass) in a field can describe the amount of CO\(_2\) in the atmosphere absorbed by plants. The greater the biomass of cocoa plants, the higher amount of CO\(_2\) absorbed, therefore, atmospheric CO\(_2\) content will decrease.

Under optimum conditions, the rate of photosynthesis of cocoa reaches 7.5 mg CO\(_2\) per dm\(^2\) of leaf area [6] or equivalent with 60 mg per dm\(^2\) per day assuming that the photosynthesis takes place from 8:00 am to 16:00 pm [7]. Cocoa plants have the ability to absorb CO\(_2\) of 80,000 kg / ha / year by releasing CO\(_2\) of 63,000 kg / ha / year so that the net uptake every year reaches 73,000 kg / ha / year to be converted into carbohydrates [7].

The most ideal measurement of biomass in plants is to use a destructive method by weighing the dry weight of the entire plant. However, it is impossible to measure productive and large size annual plants. Therefore, an allometric approach is needed. Measurement of plant biomass using allometric equations is a method that has been developed to estimate carbon stored in plant bodies. Geometrically plant biomass has a relationship that is parallel to the diameter of the plant, the density of wood and plant height [8]. The basic principle of the allometric approach is that the plant canopy is assumed to be a tube, therefore, the calculation of plant volume is based on the formula of plant volume. Measurement of plant biomass is reported to be approachable based on plant height [6] and stem diameter [9].

Cocoa is a crop that requires shade for optimal growth so that it is managed with an agroforestry system. Agroforestry is an appropriate land use system to support sustainable agriculture. Besides having a real and diverse production contribution, agroforestry also functions to conserve the environment and social conditions so as to ensure a wider economy and higher food security. Thus, cocoa plantations have the potential to play a dual role, namely as producers of commodities of economic value and as environmental conservation. This research is expected to be able to know the level of carbon uptake of cocoa plants in various types of cropping systems that have been implemented in South Sulawesi and to find out the right strategies for developing cocoa plantations so that they contribute to climate change mitigation in South Sulawesi.

2. Methodology

The research was conducted in three regencies in Sout Sulawesi Province, with 3 (three) selected districts for each regency namely East Luwu Regency (Burai, Wotu and Mumpangana Districts), Pinrang Regency (Patampanua, Batulappa and Lembang Districts), and Bantaeng Regency (Gantarangkeke, Tompobulu, and Eremerasa Districts). Soil analysis was carried out at the Soil Science Laboratory of the Faculty of Agriculture, Universitas Hasanuddin.

2.1. Data analysis

Three categories of cocoa plantations used as the research indicators, namely (K0) cocoa plantations as a control (without rare shade/shade), (K1) cocoa plantations with monoculture shade and (K2) cocoa plantations with diverse shades or multistrata. The measurement of dry weight conducted was distinguished from the main plant biomass, biomass of shade plants or other trees, necromass, and understorey biomass.
Data analysis was performed on the data collected for vegetation types of land cover both trees and understory. In addition, 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 [10] were used as shown in Table 1.

Table 1. Allometric equations for determination of the biomass of trees in a cocoa plantation

| Tree       | $\rho$ | Allometric Formula | Source |
|------------|--------|--------------------|--------|
| Cacao      |        | $BK = 0.1208 \ D^{1.98}$ | [13]   |
| Gamal      | 0.74   | $BK = 0.11 \ \rho \ D^{2.62}$ | [10]   |
| Clove      | 1.20   | $BK = 0.11 \ \rho \ D^{2.62}$ | [10]   |
| Coconut    | 0.66   | $BK = 0.11 \ \rho \ D^{2.62}$ | [10]   |
| Banana     |        | $BK = 0.030 \ D^{2.13}$ | [14]   |

Where:

- $BK$ = Dry weight (kg / tree)
- $D$ = tree diameter or dbh (1.3 m)
- $\rho$ = wood specific gravity (g / cm3)

2.2. Implementation stage

The activity began with the preparation of sample plots and continued with data collection on trees, understory, necromass (litter), and soil.

2.2.1. Preparation of the sample plot. Sample plots were made with a size of 40 m x 5 m on study site that contained the most types of plants. Observation plots were measured with a meter and pegged at each angle then wrapped around a raffia rope as a sample plot boundary.

2.2.2. Data collection of trees, plants, and necromass. For estimating tree biomass, tree data collected were diameter, height, species, and specific gravity. Measurement of tree diameter was conducted on all tree species in the sample plot using non-destructive method at a height of 1.3 m from the ground surface (Diameter at Chest Height or Diameter at Breast Height = DBH). The height of the trees was conducted using a hetereter.

For the estimation of biomass of the understorey plant, measurement were made on dry weight of the plant. All plants specified as lower strata species were recorded and collected destructively in a 1 m x 1 m plot and placed in an envelope and labelled for each sample plot. Furthermore, the plants were weighed to record the fresh weight. For the dry weight of plant biomass, a sample of 300 g was taken as a sub-sample or if the plant biomass is <300g, then all sample plants taken as sub-sample. The sample then dried at 80 °C for 48 hours or until it reaches a constant dry weight. For estimating necromass and litter biomass, the fresh and dry weight of the necromass were recorded. All litter types (in 1 m x 1 m plots) representing thick, medium and rare necromass as much as, 10 samples, were put in a container and labelled, then weighed for their fresh weight. As for the dry weight of necromass biomass, a 300 g of the necromass was taken as a sub sample and if the necromass is <300g, then all the necromass was used as a sub sample. The necromass sample was dried at 80 °C for 48 hours or until it reaches a constant dry weight. Similarly, all dead trees in the sample plot were measured for diameter and height. A samples of the woods with a dimension of 10 cm x 10 cm x 10 cm were taken to measure for the fresh and dry weight. The samples of the dead trees was dried in an oven at 80 °C for 48 hours prior to dry weight measurement.

2.2.3. Land data retrieval. For soil C estimation, soil sampling is performed on each sample plot and soil analysis is carried out to obtain data on soil texture, soil density, pH, CEC, and organic C.
3. Results and Discussion

3.1. Carbon stored

The results of the calculation of stored carbon in three regencies in South Sulawesi indicate that variations in the composition of plant species in the cocoa plantation resulted in variations in the amount of carbon stored in a planting area. Details of the amount of carbon stored in various plant species compositions in various cropping patterns are presented in Table 2.

Table 2. Amount of carbon stored in various patterns of plant type composition in South Sulawesi cocoa plantation

| Regency | District | Location | Cropping Patterns | Carbon Sequestration (t/ha) | Total C (t/ha) |
|---------|----------|----------|-------------------|----------------------------|---------------|
| **East** | **Luwu** | Burau | Jalajja | K2 | 13.28 | 4.95 | 7.43 | 2.66 | 11.97 | 40.28 |
| | | | Kalaena | K2 | 7.54 | 7.05 | 10.58 | 1.51 | 7.18 | 33.85 |
| | | Wotu | Tarengge | K1 | 4.60 | 3.20 | 4.80 | 0.92 | 6.04 | 19.55 |
| | | | Cendana Hijau | K2 | 25.38 | 4.30 | 6.45 | 5.08 | 7.22 | 48.42 |
| | | Mangkutana | Balaikembang | K1 | 10.41 | 5.20 | 7.80 | 2.08 | 5.21 | 30.69 |
| | | | Wonorejo Timur | K2 | 5.66 | 4.00 | 6.00 | 1.13 | 9.58 | 26.37 |
| **Average** | | | | | 33.19 |
| **Pinrang** | Patampanua | Tonyamang | K2 | 7.58 | 2.70 | 4.05 | 1.52 | 4.53 | 20.37 |
| | Sipatuo | | K2 | 7.17 | 2.35 | 3.53 | 1.43 | 3.94 | 18.42 |
| | Tapple | Tapporang | K1 | 7.98 | 2.05 | 3.08 | 1.60 | 6.80 | 21.51 |
| | Kassa | | K2 | 9.81 | 2.50 | 3.75 | 1.96 | 10.61 | 28.63 |
| | Lembang | Benteng | K2 | 9.28 | 2.95 | 4.43 | 1.86 | 11.10 | 29.61 |
| | | Paremba | | | | | | | |
| | | Betteng | K2 | 13.91 | 2.45 | 3.68 | 2.78 | 11.84 | 34.65 |
| **Average** | | | | | 25.53 |
| **Bantaeng** | Gantarangkeke | Gantarangkeke | K2 | 15.43 | 2.05 | 3.08 | 3.09 | 10.18 | 33.82 |
| | Tompopulu | Patalassang | K2 | 19.21 | 2.20 | 3.30 | 3.84 | 12.99 | 41.54 |
| | Tombolo | | K1 | 10.21 | 2.75 | 4.13 | 2.04 | 7.89 | 27.02 |
| | Eremerasa | Barua | K1 | 8.99 | 2.45 | 3.68 | 1.80 | 10.24 | 27.15 |
| **Average** | | | | | 32.38 |

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

Table 2 shows that the composition of plants in cocoa plantations with K2 pattern absorbs the most carbon. This illustrates that the agroforestry cocoa cultivation pattern is right to support sustainable agriculture. Aside from making tangible and diverse contributions, agroforestry 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.

3.2. Carbon emissions

Carbon emissions from land cover changes from plantations to plantations based on historical land use. The carbon stored in plantation forests in Sulawesi [10] is 92.65 t / ha. Thus the carbon emissions that occur in East Luwu Regency are:

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

While carbon emissions in Pinrang Regency are:

\[ \Delta CA = 92.65 - 25.53 = 67.12 \text{ t / ha} \]
The carbon emissions in Bantaeng Regency are:

\[ \Delta CA = 92.65 - 32.38 = 60.07 \text{ t / ha} \]

Based on calculations from the three regencies, the composition of land cover that is quite dense will give the lowest carbon emissions (59.46 ton/ha) that occurred in East Luwu District while the land cover composition that provides the biggest carbon emissions (76.12 ton/ha) occurred in Pinrang Regency.

3.3. 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 [11]. The amount of CO₂ content in the composition of land cover types in East Luwu Regency is 3.67 x 33.19 ton C / ha = 121.81 ton CO₂ / ha, the composition of land cover types in Pinrang Regency is 3.67 x 25.53 ton C / ha = 93.69 ton of CO₂ / ha, and the composition of the type of land cover in Bantaeng Regency is 3.67 x 32.07 tons C / ha = 117.70 ton of CO₂ / ha.

4. Conclusions
Based on the results of the calculation of carbon stored in a cocoa plantation in South Sulawesi it can be concluded that the level of carbon uptake in East Luwu Regency is 33.19 ton C/ha, in Pinrang Regency 25.52 ton C/ha, and Bantaeng Regency 32.07 ton C/ha. The amount of carbon emissions absorbed in East Luwu Regency is 57.46 t/ha, Pinrang Regency 67.12 t/ha, and Bantaeng Regency 60.07 ton/ha. CO₂ content based on the composition of the existing land cover in East Luwu Regency is 121.81 ton CO₂/ha, Pinrang Regency 93.69 tons CO₂/ha, and Bantaeng Regency 117.70 tons CO₂/ha. The right strategy in developing a cocoa plantation is by applying the K2 planting pattern technique, which is a diverse or multistrata cacao plantation known as an agroforestry system.

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