The role of agroforestry based cocoa on climate change mitigation: A review

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Abstract. The agroforestry approach is considered the best option for the development of cocoa cultivation in the future. It combined the forest trees as shade plants and cocoa as the main crop on the same land. The farmers are widely adopting agroforestry due to some benefits such as conserving soil water, nutrient, microorganism, and providing a suitable microclimate for cocoa. Here, we reviewed the current research reports on the role of agroforestry based on the perspective of climate change mitigation. It included the point (1) agroforestry based on cocoa could improve total biomass (above and below ground), CO$_2$ absorption, and carbon deposit CO$_2$, (2) carbon sequestration levels of cocoa depending on the forest trees species as shade and location.

Keywords: Theobroma cacao, agroforestry, carbon, climate, mitigation.

1. Introduction

Every year, approximately 130,000 ha of agricultural land undergoes a variety of changes as a result of the practice of converting agricultural land to non-agricultural areas. Typically, agricultural conversion is done for long-term development projects like houses, factories, roads, and other public facilities [1]. Because of this condition, agricultural land is in limited supply. Limited agricultural land and increasing supply for plantation crops, including cocoa, have led to an increase in agricultural land extensification. In practice, extensification is still accomplished through deforestation. The area of the Business Permit for the Use of Timber Products, the Gross Regional Domestic Product, Forestry and Logging subcategories, and non-forest areas (agriculture and mining), have a positive impact on deforestation [2]. In Indonesia, deforestation totaled 462,458 ha in 2018-2019 [3].

Deforestation has a severe influence on the environment and contributes to climate change. Deforestation leads to environmental pollution by reducing soil fertility, decreasing soil water content, and raising the rate of soil erosion and landslides. Climate change is exacerbated by ongoing environmental damage caused by deforestation. Climate change is caused by rising sea levels, increasing temperatures, long dry seasons, low groundwater content, and heavy rainfall. Carbon dioxide (CO$_2$), methane (CH$_4$), and nitrous oxide (N$_2$O) are the three principal greenhouse gases that influence climate change [4]. As human activities that use fossil fuels for power generation, transportation, industry, and land-use change to provide new land for agriculture (including plantations) and settlements increase, so does the concentration of greenhouse gases. Indonesia's total increase in GHG emissions was 44.36 percent from 2000 to 2014, with an average annual growth of 2.20 percent. Land use, land-use change, and forestry (LULUCF) contributed the most to GHG emissions, accounting for 34.14 percent of total emissions, followed by the energy sector, which accounted for 31.98 percent. The remainder came from...
the peat sector (16.68%), the agricultural sector (8.07%), the waste treatment sector (6.10%), and the industrial process and product use sector (3.03%). The land sector is formed by combining the LULUCF and peat sectors, making it the sector with the highest emissions (50.82 percent). Deforestation and land conversion, which are caused by the exploitation of mining and other natural resources, account for 60-70 percent of GHG emissions on a national scale [5]. According to the national action plan to reduce GHG emissions, the target for reducing greenhouse gas emissions in 2020 is 0.767 gigatonnes CO₂e (26%) but is expected to increase by 15% to 41% with international funding support. According to the national action plan to reduce GHG emissions, the target for reducing greenhouse gas emissions in 2020 is 0.767 Gigaton CO₂e (26%) but is expected to increase by 15% to 41% with international funding support [6]. If supported by the government, the program to minimize GHG emissions in agriculture has a target of 0.008 Gigaton CO₂e, but it is expected to reduce emissions by 0.011 Gigaton CO₂e if funded by the international community. According to the national GHG inventory calculation, GHG emissions in 2018 totaled 1,637,156 Gg CO₂e, with agriculture accounting for 131,642 Gg CO₂e (8 percent from total national emissions)[7]. Several agricultural activities, including livestock (manure management), burning of agricultural residue biomass, burning of agricultural residue biomass and shifting agriculture, application of agricultural lime, application of urea fertilizer, direct and indirect N₂O emissions from managed soil, and emissions from lowland rice, contribute to greenhouse gas emissions [7].

To decrease the rate of deforestation in Indonesia, various methods and policies are implemented. There are six scenarios in the action plan for reducing GHG emissions in the forestry sector to meet the NDC target in 2030, namely by reducing deforestation (0.45-0.325 Mha.year⁻¹) and expanding the use of forest management principles that are environmentally friendly (natural and plantation forest), rehabilitation of 12 million ha of damaged land, restoration of 2 million peatlands, and forest fire suppression [7]. In addition to these programs, there are programs for sustainable peat management, reduced deforestation and land degradation, carbon sequestration development, and solid and liquid waste reduction [8]. Agroforestry is a development of existing policies in the fields of agriculture and forestry from several policy action plans to reduce greenhouse gas emissions. Agroforestry plays a role in existing policies, such as reducing the rate of deforestation and land degradation and developing carbon sequestration. Cocoa-based agroforestry is one of the agroforestry models developed in Indonesia. This agroforestry model can provide nearly identical ecosystem services to forests while also addressing social, economic, and ecological (conservation) concerns [9]. The purpose of this paper is to identify the environmental impact of cocoa-based agroforestry, particularly in terms of climate change mitigation.

2. The effects of climate change
In the twenty-first century, climate change is becoming more severe. This is due to increased greenhouse gas emissions. The rise in greenhouse gas emissions has not been accompanied by an increase in carbon stocks in soil or vegetation. The effects of global warming ranging from moderate to high risk include water scarcity on dry land, soil erosion, loss of vegetation, crop damage due to forest fires, melting of ice sheets, coastal degradation, and reduced tropical crop yields [10]. Between 1850 and 1900, the average ground surface temperature increased by 1.53°C (1.38-1.68°C). Although the worldwide mean surface temperature rose by 0.87°C (0.75-0.99°C) [10]. An increase in air temperature around 1.5°C due to global warming has risks ranging from water scarcity on dry land, damage from forest fires, ice sheet degradation, and food supply instability. An increase in air temperature of about 2°C global warmings, the risk of ice sheet degradation, and food supply instability. In addition, at around 3°C the risks from global warming are loss of vegetation, damage from forest fires, and water scarcity on land [10].

Increased use of fossil fuels for the production of agricultural chemicals, the process of making organic fertilizers, the decomposition of organic matter, and the disposal of livestock manure all contribute to an increase in GHG in agriculture. Agricultural, forestry, and other land-use activities accounted for approximately 13% of CO₂, 44% of CH₄, and 81% of N₂O emissions from human activities worldwide between 2007 and 2016, accounting for 23% (12.0 Gigaton CO₂ yr⁻¹). The natural effect of soil on environmental changes caused by human activity accounts for approximately 11.2
Gigaton CO₂ yr⁻¹ or 29% of total CO₂ emissions. Emissions from all pre-production and post-production activities in the global food system are estimated to be 21–37% of total anthropogenic net GHG emissions [10]. Increased CO₂ gas concentrations in the atmosphere caused by humans have contributed to an increase in global temperatures and, as a result, sea-level rise. According to the IPCC [10] report, the average global sea-level could rise by 0.52-0.98 m by the end of the twenty-first century. Each 1 degree fahrenheit increase in temperature can result in a 1% increase in rainfall [11]. Climate change has an impact on the agricultural sector, which contributes to the increase in greenhouse gases [12]. Climate change has an impact on rice crop production [13], cashew nut production [14], and arabica coffee production [15], rubber and robusta coffee [17, 18]. Farmers’ behavior and income are also affected by climate change [18–20]. According to Owoeye and Sekumade [21], climate change in Nigeria causes: (1) the occurrence of fruit rot disease (80%), (2) the death of cocoa trees (75%), an increase in Helopeltis attacks (65%), a decrease in cocoa yields (63%), and the inability to dry cocoa pods (61%). Rainfall has a short-term positive effect on cocoa yields but has no long-term effect. Indeed, the long-term consequences are negative. Unlike rainfall, the temperature has a short-term negative impact on cocoa yields but a long-term positive impact [22].

3. Mitigation of climate change

Mitigation is an attempt to prevent, slow, and reduce climate change by lowering greenhouse gas emissions [23]. There are methods for reducing greenhouse gases and increasing carbon stocks that can be used in mitigation efforts. According to Indonesia’s commitment through the Nationally Determined Contribution (NDC) document, the national greenhouse gas emission reduction target for 2030 is 834 million tons of CO₂e unconditionally (CM1) and 1,081 million tons of CO₂e conditionally (CM2) [7]. Climate change mitigation in agriculture can be accomplished through the use of various cultivation technologies such as eco-friendly land management, organic mulch application, rorak creating, the use of superior planting materials, development and rejuvenation of old plants, the planting of more diverse shade plants, the planting of temporary shade, the pruning of main crops, the use of organic fertilizers, and the planting of cover crops, can help to adapt and mitigate climate change [24]. According to Adib [11], technological adaptations to climate change can be made, such as adjusting planting time to the weather, developing water-saving water management technology, immersing plant residues in the soil, minimum tillage, direct seed sowing, and implementing good agricultural practices. The agricultural action plan for reducing greenhouse gas emissions is based on the guidelines for implementing the agricultural action plan for reducing greenhouse gas emissions, which include implementing the introduction of low-emission varieties, irrigation water efficiency, and the use of organic fertilizers [6]. According to Putri [25], the use of ex-mining land for soybean plants with no-tillage or minimal tillage had an effect on soil CO₂ emissions at the 78th curry after planting. CO₂ emissions are lower in a no-tillage system than in a minimum-tillage or intensive-tillage system. Yulianingrum [26] present an environmentally friendly technology package, one of which is the use of low-emission varieties in paddy field cultivation with a total CH₄ emission of 0.324 ton.ha⁻¹.season⁻¹, 0.047 ton.ha⁻¹.season⁻¹ less than conventional systems. Mitigation actions from the agricultural sector, specifically the use of plant cultivation technology (12.41 million tons of CO₂e), the use of organic fertilizers and biopesticides (0.064 million tons of CO₂e), the utilization of livestock manure/urine, and agricultural waste for biogas (0.19 million tons of CO₂e), and the use of organic fertilizers and biopesticides (0.064 million tons of CO₂e) [7]. GHG emissions from the agricultural sector were 131.64 million tons CO₂e in 2018 (figure 1a), while baseline NDC emissions (BAU) were 115.03 million tons CO₂e, resulting in an NDC 2030 contribution of -16.61 million tons CO₂e. MTon CO₂e (-0.59 percent).
Aside from the agricultural sector, efforts to mitigate climate change are made in a variety of ways, including reducing deforestation, reducing forest degradation, implementing sustainable forest management (low impact logging techniques, sustainable forest management techniques, and natural regeneration), and increasing carbon stocks (land rehabilitation, planting enrichment, plantation foresight) [27], enhancing the importance of high-value conservation and peat management (management based on land cover type, groundwater table methods, and peat fires) [7]. In 2018, the forestry sector was mitigated by reducing deforestation by 96 million tons of CO$_2$e and controlling forest fires by 104 million tons of CO$_2$e [7]. The use of intercropping crop cultivation technology can help to support action efforts to reduce the largest greenhouse gas emissions from these two sectors. Agroforestry is a type of cropping pattern that combines forest trees and plantation crops [28]. Agroforestry is also a collaborative system between agriculture and forestry to increase agricultural product yield on forest land while minimizing deforestation. The forestry sector reduced GHG emissions by 760.76 million tons of CO$_2$e, which was higher than the baseline of 723.51 million tons of CO$_2$e, for a difference of 37.25 million tons of CO$_2$e (1.29 percent) [7].

4. Agroforestry fundamentals

Agroforestry is a sustainable land management system that preserves biodiversity, feeds ecosystems, conserves water and soil, and provides economic benefits to farmers. According to Jose [29], the four main benefits of agroforestry are carbon sequestration, maintaining and increasing soil fertility, biodiversity conservation, and maintaining and improving air and water quality. Then, according to Sanchez [30], profitable agroforestry systems have the potential to be sustainable, control erosion, increase biodiversity, and conserve carbon, as long as nutrient absorption is balanced with nutrient recovery through litter and strategic use of fertilizers, particularly phosphorus. Asare [31] defines cocoa agroforestry as the strategic incorporation of suitable and valuable non-cocoa tree species and other crops into cocoa plantations over time and space. Agroforestry is an innovation in sustaining the decline in cocoa production for cocoa plants that require shade.

The development of agroforestry land from various types of wood plants has a positive environmental impact by protecting flora and fauna. According to Suryani and Dariah [32], agroforestry is a land management system that combines forest plants and plantation crops to increase land yields while preserving the environment and achieving community welfare. Agroforestry systems are typically built around food crops and plantation crops. Furthermore, agroforestry has the potential to reduce global warming [8]. According to research conducted in Bangladesh's Jessore District [33], agroforestry promotes proper resource use; promotes environmentally friendly, socioeconomically sound, and economically viable sustainable production and livelihood systems through diversification of inputs and outputs, indicating that agroforestry is a sustainable system in Bangladesh.

In climate change mitigation efforts, forest areas are used in three ways: carbon storage areas, carbon sink areas, and carbon prevention areas [27]. Butarbutar [34] claims that agroforestry aids adaptation efforts by transferring germplasm, local genetic adaptation, and the role of species plasticity, while mitigation efforts include carbon sequestration, carbon protection, and the use of renewable energy. The
vegetation on it has a strong influence on agroforestry to reduce carbon stocks [35]. The total carbon stock in various land uses shows that tropical rainforest has the highest total carbon stock at 455 Mg C.ha\(^{-1}\), while corn has the lowest at 57.67 Mg C.ha\(^{-1}\) [35]. Carbon stocks in general agroforestry systems can range from 92 MgC.ha\(^{-1}\) to 174 MgC.ha\(^{-1}\) [36].

There is an increasing number of agroforestry systems based on plantation crops such as coffee and cocoa. To grow, these plants require shade plants, which can be obtained by combining forestry plants such as teak, mahogany, jabon, sengon, and eucalyptus, among others. Agroforestry with a terraced canopy system and sengon, coffee, cocoa, mango, rambutan, and pomelo has total aboveground biomass of 17.99 Mg.ha\(^{-1}\), with 85 % tree biomass, 13 % herbaceous vegetation, and 2 % plant litter. Agroforestry contains 45 percent trees, 26.51 % herbaceous vegetation, 34.63 % plant litter, and 2.42 % soil. This agroforestry has a carbon stock of 7.64 MgC.ha\(^{-1}\) (8%) aboveground and 84.69 MgC.ha\(^{-1}\) (92%) belowground [36]. The secondary forest has a total carbon stock value of 265.86 ton.ha\(^{-1}\), which is higher than agroforestry, which has a carbon stock value of 131.31 ton.ha\(^{-1}\), oil palm plantation, which has a carbon stock value of 100.89 ton.ha\(^{-1}\), and rice field, which has a carbon stock value of 70.50 ton.ha\(^{-1}\) (Figure. 2) [37].

![Figure 2. Depicts total carbon stocks across various land uses [37].](image)

Agroforestry systems based on cocoa are a combination of trees (for shade) and cocoa plants (for cultivation) on the same land [28]. Farmers have long used cocoa-based agroforestry systems, which are now regarded as a promising form of multifunctional agriculture. Farmers developed cocoa-based agroforestry that provides environmental services such as (1) conservation of land, water, and biodiversity, (2) addition of soil nutrients, (3) control of microclimate, and (4) addition of additional soil water content. Cocoa agroforestry can also help to mitigate climate change by increasing biomass and carbon stock, which reduces GHG (CO\(_2\)) emissions. The terraced plant canopy of shade trees, cocoa, and other plants can absorb carbon dioxide, which is becoming more of an issue in climate change.

5. Growing agroforestry practices in the neighborhood
Farmers choose agroforestry systems based on income, production continuity, production speed, ease of maintenance, local culture, and the ability of plants to be planted with other crops in changing crop types and cropping patterns. The Damar agroforestry management research in South Lampung concluded that there were two best cropping patterns based on these factors. The first cropping pattern combines cocoa as the primary crop with cloves, bananas, petai, Tangkil, and durian as secondary crops, whereas the second cropping pattern combines resin as the primary crop with cloves, durian, coconut, and petai as secondary crops [38]. Manglid agroforestry patterns in Tasik Malaya contribute to the conservation of plant species diversity and are multi-beneficial, despite being relatively low in terms of biodiversity and plant species richness [39]. Cocoa is a sun-loving plant. Plants that can be planted alongside other shade plants and protected from some of the suns, according to Wahyudi [40]. According to Asante [41], the best trees for providing shade in cocoa agroforestry systems in the Bonsu Nkwanta landscape are *Pycnanthus angolense, Amphimas pterocarpoides, Ricinodendron heudelotti,*
Triplochiton scleroxylon, Ceiba pentandra, Spathodea campanulata, Milicia excelsa, Piptadeniastrum africanum, and Canarium sweinfurthii because it has an upper canopy that spreads to a cylindrical and elongated canopy. According to research conducted in the Pasaman District of West Sumatra, the cocoa-based agroforestry model influences cocoa productivity [42]. This study discovered that the simple agroforestry system produced the most cocoa (596.39 kg. ha\(^{-1}\)), followed by the non-agroforestry system 400.46 kg. ha\(^{-1}\), and the complex agroforestry system 397.03 kg. ha\(^{-1}\) (Figure 3).

![Cocoa Productivity](image)

**Figure 3.** Histogram of cocoa productivity in different cocoa plantation management systems [42].

6. Climate change mitigation roles and functions of cocoa-based agroforestry

A cocoa-based agroforestry system is a cocoa cultivation system that makes use of several trees that serve as shade plants. The cocoa agroforestry system will include multi strata shade plants, allowing for the storage of a large amount of carbon [43–46]. Faradilla [43] compared the carbon stock that can be stored in cocoa plantations with agroforestry systems to monoculture cocoa plantations in three regions of South Sulawesi. According to the study’s findings, the cocoa-based agroforestry system with multi strata shelters has a total carbon stock of 124.69 tons. ha\(^{-1}\) (Table 1), which is higher than the monoculture cocoa stock of 91.7 tons. ha\(^{-1}\). The same study in South Sulawesi’s Pinrang region found that monoculture cocoa plantations had a total carbon of 21.51 tons. ha\(^{-1}\), while multi strata cocoa-based agroforestry had an average of 26.34 tons. ha\(^{-1}\) [45]. According to Asrul [44], the multistrata cocoa agroforestry system has a higher carbon stock of 37.68 ton. ha\(^{-1}\) when compared to the 27.09 ton. ha\(^{-1}\) monoculture cocoa grown in Bantaeng, South Sulawesi.

| Sub district   | Cropping patterns       | Plot | Above ground carbon (tons. ha\(^{-1}\)) | Below ground carbon (tons. ha\(^{-1}\)) | Total carbon (tons. ha\(^{-1}\)) |
|----------------|-------------------------|------|----------------------------------------|----------------------------------------|-------------------------------|
| Burau          | Cocoa monoculture       | 1    | 28.73                                  | 68.15                                  | 96.88                         |
|                |                         | 2    | 27.38                                  | 64.56                                  | 91.94                         |
|                |                         | 3    | 30.64                                  | 59.15                                  | 89.79                         |
| Wotu           | Cocoa monoculture       | 1    | 35.64                                  | 52.21                                  | 87.85                         |
|                |                         | 2    | 38.35                                  | 50.57                                  | 88.92                         |
|                |                         | 3    | 33.18                                  | 47.86                                  | 81.04                         |
| Mangkutana     | Cocoa monoculture       | 1    | 22.03                                  | 78.42                                  | 100.45                        |
|                |                         | 2    | 26.94                                  | 66.83                                  | 93.77                         |
|                |                         | 3    | 38.09                                  | 56.51                                  | 94.6                          |
| Burau          | Average                 |      | 31.2                                   | 60.5                                   | 91.7                          |
|                | Cocoa multi strata shades| 1    | 29.8                                   | 95.72                                  | 125.52                        |
|                |                         | 2    | 43.34                                  | 85.76                                  | 129.1                         |

Table 1. Shows the carbon stock of cocoa agroforestry systems and cocoa monocultures in three different areas of East Luwu, South Sulawesi (ton. ha\(^{-1}\)) [43].
The density of shade plants in cocoa-based agroforestry systems affects biomass and carbon stocks differently. The higher the carbon stock and biomass in the cocoa-based agroforestry system, the denser the population (Figure 4). Carbon storage ha\(^{-1}\) varies significantly in Nigeria between sparse cocoa agroforestry, dense cocoa agroforestry, and natural forest, according to aboveground carbon storage. The natural forest has the highest carbon storage value of 184.99 ton ha\(^{-1}\), followed by dense cocoa agroforestry at 57.5 ton ha\(^{-1}\) and rare cocoa agroforestry at 16.6 ton ha\(^{-1}\) [46].

### Table 1

| Sub district | Cropping patterns                  | Plot | Above ground carbon (ton ha\(^{-1}\)) | Below ground carbon (ton ha\(^{-1}\)) | Total carbon (ton ha\(^{-1}\)) |
|--------------|------------------------------------|------|---------------------------------------|---------------------------------------|-------------------------------|
| Wotu         | Cocoa multi strata shades           | 3    | 26.67                                 | 92.86                                 | 119.53                        |
|              |                                    | 1    | 47.63                                 | 77.96                                 | 125.59                        |
|              |                                    | 2    | 24.68                                 | 73.92                                 | 98.59                         |
|              |                                    | 3    | 38.05                                 | 93.85                                 | 131.9                         |
| Mangkutana   | Cocoa multi strata shades           | 1    | 29.53                                 | 89.3                                  | 118.83                        |
|              |                                    | 2    | 41.5                                  | 101.69                                | 143.19                        |
|              |                                    | 3    | 37.21                                 | 92.75                                 | 129.96                        |
| Average      |                                    |      | 35.38                                 | 89.31                                 | 124.69                        |

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![Figure 4. Biomass and carbon stock in treatments with sparse cocoa agroforestry, cocoa agroforestry on, and natural forest [46].](image)

The carbon stock above the plant is usually greater than the carbon stock below ground. Understorey, coarse woody debris, and fine litter/brown waste are all part of the above-ground carbon stock. While underground carbon includes the absorption of carbon by roots and soil. According to research Gockowski [47] conducted in Cameroon, the tropical bottom forest ecosystem has a carbon stock of 227 tons ha\(^{-1}\), cocoa-based agroforestry has a carbon stock of 88.7 tons ha\(^{-1}\) and cocoa without shade have a carbon stock of 49.1 tons ha\(^{-1}\). The total underground carbon stock did not differ; the carbon stock in primary forest was 45.4 tons ha\(^{-1}\), 43.2 tons ha\(^{-1}\) in cocoa-based agroforestry, and 43.2 tons ha\(^{-1}\) in cocoa without shade. Norgrove and Hauser [48] also compared the carbon content stored at the top and bottom of planting in basic tropical forest ecosystems with cocoa-based agroforestry, finding a difference of 58.2 tons ha\(^{-1}\) and 1.1 tons ha\(^{-1}\). Carbon stock has a strong relationship with plant vegetation biomass. The higher a vegetation's biomass content, the higher its carbon stock content [49]. The amount of biomass is highly dependent on the vegetation that grows on it. With 541.2 tons ha\(^{-1}\), 304.5 tons ha\(^{-1}\), and 85.3 tons ha\(^{-1}\), respectively, the primary forest has more biomass than cocoa agroforestry and food crops [49]. The amount of biomass is highly dependent on the vegetation that grows on it. With 541.2 tons ha\(^{-1}\), 304.5 tons ha\(^{-1}\), and 85.3 tons ha\(^{-1}\), respectively, the primary forest has more biomass than cocoa agroforestry and food crops [49]. A separate study, conducted by Gama-Rodrigues [50], revealed
that natural forest soil carbon stocks were lower than those of cocoa + *Erythrina* spp agroforestry. + *Gliricidia* spp and cocoa + *Erythrina* spp, as shown in figure 5.

**Figure 5.** Soil carbon content in soil layers 1-100 cm treated with natural forest, cocoa + *Erythrina* spp. + *Gliricidia* spp., and cocoa + *Erythrina* spp [50].

### 7. Conclusions

One of the causes of the increase in greenhouse gas emissions is the practice of converting agricultural land to non-agricultural areas. Then, in the twenty-first century, climate change boosted a significant increase in greenhouse gas emissions. A mitigation program is an effort to prevent, slow, and reduce climate change by reducing greenhouse gas emissions. Agroforestry is one of the mitigation efforts in reducing carbon emissions, and it is a policy that exists between agricultural and forestry policies. Aside from its ability to reduce global warming, agroforestry can be a long-term effort in mitigating the negative effects of environmental changes, such as erosion control. According to the findings of this paper, agroforestry-based cocoa has more biomass than monoculture cocoa. Cocoa-based agroforestry could increase total biomass (above and below ground), CO₂ absorption, and carbon stock. Cocoa agroforestry carbon sequestration levels are determined by the population of shade trees, the species of forest trees, and the location.

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