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Trade-off between carbon offset and economic benefit: Potential of cocoa-based agroforestry systems in the voluntary carbon market

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Abstract

Agroforestry systems (AFS) are a viable option for the mitigation of deforestation. Thus far AFS has been recognised and financed through the Voluntary Carbon Market (VCM) program; however, analysis of the potential carbon credit payment and productivity trade-off has rarely been conducted. This study aims to analyse the potential of cocoa-based AFS in terms of the trade-off of carbon accumulation and productivity in West Sumatra, Indonesia. The trade-off is shown through 20 years of financial analysis between the two schemes: AFS without the VCM scheme (agroforestry Business as Usual-aBAU); and AFS with the VCM scheme. A comparison is made between four types of cocoa plantations in West Sumatra: (i) Cocoa-Rubber (CR), (ii) Cocoa Multi-strata (CM), (iii) Cocoa-Coconut (CC), and (iv) Monoculture practice (M). The results showed that under the aBAU scheme, CC showed the highest Net Present Value (NPV) and Benefit Cost Ratio (BCR) of \$6,647 USD and 5.8 respectively, while the lowest was CR, with an NPV and BCR of \$2,423 USD and 2.73, respectively. Cocoa monoculture presented the group with the fastest payback period (PP) of two years. Utilising a VCM scheme under the Plan Vivo standard with Voluntary Emission Reduction (VER) as a selling unit, cocoa farmers stand to gain NPV by 15-25 % at VER prices of \$8 USD Mg CO_2e^{-1}. It is thus concluded that cocoa-based AFS could be adopted under the VCM scheme with the dual purposes of enhancing carbon-storage through AFS and greater income for farmers.

Keywords: *Theobroma cacao*, carbon trade-off

1 Introduction

Indonesia suffers one of the highest rates of deforestation, specifically of primary forests, in Asia and subsequently is also one of the largest emitters of greenhouse gases (GHG) in due to the destruction of pristine forests and bogs, with deforestation identified as the largest contributor (Margono *et al*., 2014, Austin *et al*., 2018, Darkwah *et al*., 2018). The Indonesian Ministry of Forestry and Environment estimates that 462,000 hectares of forest was lost both legally and otherwise within a period of one year (2018-2019). This number is derived from satellite imagery monitoring by subtracting the gross loss of canopy value from the reforestation rate of 31,000 ha (MOEF 2016, MOEF 2020a). Indonesia currently also suffers from the highest rate of deforestation of secondary forests, with 162,800 ha (MOEF 2020a). The Indonesian government has responded with the adoption of various temporal and spatial conservation strategies to reduce the rate of deforestation. These strategies include the establishment and management of restricted and protected primary forests, strictly regulated forestry, managed forestry, the controlled conversion of secondary forests into plantations and farmland with each category representing roughly 20 % of total canopy cover (MOEF 2020b,c).

The promotion of agroforestry systems (AFS) as opposed to monoculture plantations has also been considered, specifically in the areas slated as traditional and social forests, which are under the control of local communities (MOEF 2020a,c,d). AFS has been considered a traditional form of forest management in Indonesia with timber, fruit, medicinal herb plantations along with primary and secondary crop plantations are among the various types developed by local communities. Along the northern and eastern coastlines of the island of Java, teak is the dominant tree within the agroforestry system with timber as the primary product

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(Roziaty *et al*, 2020) while palm oil, rubber and cocoa dominate agroforestry systems in West Sumatra.

The traditional method of forest management in West Sumatra is the *parak* system, which is a complex agroforest which involves the initial slash and burning of established plots, that are planted with various trees that are cyclically burned and replaced as the production rate fall due to age or due to economic trends related to the rise and fall of commodity prices (Schroth *et al*., 2004, Schroth and Harvey, 2007). With the advent of modern corporations and long-term contracts for the supply of commodities, the West Sumatra provincial government is currently promoting more sustainable models such as permanent monocultures and complex agroforests, with special focus given towards cocoa production, that do not involve the slash and burn practices inherent to cyclical AFS practices and the subsequent release of GHGs (Sefriadi *et al*., 2013, Damanik & Herman, 2015). The transition from cyclical towards permanent monoculture practices, currently favoured by local farmers, has been demonstrated to have serious effects upon biodiversity and subsequent stability of ecosystems (Santhyami *et al*., 2018).

Complex cocoa based AFS, with multiple species managed within the same area, offer increased tree biodiversity with biodiversity levels (H') scores on par with secondary forests (Schroth *et al*., 2004, Schroth & Harvey, 2007, Sefriadi *et al*., 2013, Santhyami *et al*., 2020). The increased tree biodiversity increases carbon sequestration of these agroforestry systems (Jose *et al*., 2009, Gockowski & Sonwa, 2011, Baliton *et al*., 2017, Kay *et al*., 2019). The potential carbon sequestration value of cocoa based AFS is comparable to that of secondary forests (Schroth *et al*., 2015; Santhyami *et al*., 2018). The aboveground carbon stock of cocoa based AFS ranges from 21–96 Mg C ha^{-1} in Africa (Oke & Olatiilu, 2011, Afele *et al*., 2021, Batsi *et al*., 2021), 49 Mg C ha^{-1} in Central America (Somarriba *et al*., 2013), and 47–99 Mg C ha^{-1} in Sulawesi and Sumatra Indonesia (Rajab *et al*., 2016, Santhyami *et al*., 2018). Previous studies have estimated that tropical agroforestry can store approximately 60 percent of the carbon stocks of natural forests, suggesting that 1.6 ha of optimally managed agroforestry can contribute as much to carbon conservation as 1 ha of natural forest (Kessler *et al*., 2012). Therefore, activities under cocoa based AFS are permitted in multiple Land-use, Land-use Change and Forestry (LULUCF)-based carbon markets, such as regulated carbon markets (CDM), REDD+, and voluntary carbon markets (VCM) (Angelsen & Wertz- Kanounnikoff, 2010; Netter *et al*., 2022). Thus, Cocoa based Agroforestry Systems could be considered more advantageous due to: (i) the active sequestering of carbon in plants and soils, depending on pre-converted vegetation and soil carbon; (ii) the wood products from this system can serve as sustainable substitutes for natural forest timber and wood derivatives; and (iii) the possibility of participation in VCM to increase local farmer's income.

Therefore, further research is required to assess the trade-off between the potential for carbon sequestration and the economic benefit of cocoa-based AFS as opposed to monocultures in West Sumatra. No specific carbon-productivity trade-off study for cocoa AFS in Indonesia has yet been conducted. The scale of AFS activity in Indonesia necessitates an assessment of the potential for traditional agroforestry communities to be incorporated into the global carbon trading scheme. Thus, creating incentives for local farmers to prioritise the development of complex AFS in the secondary forests that are allotted for conversion. In this study, simulations are used to calculate the carbon-productivity trade-off analysis if agroforestry practices are included in voluntary carbon market (VCM) activities. VCM is a non-regulatory mechanism that arose due to the forestry sector's difficulties in entering the Clean Development Mechanism (CDM) with AFS being one of the approved forestry activities under the VCM Scheme.

2 Materials and methods

2.1 Study area

The research was condicted in the two disctricts with the highest cocoa bean production in West Sumatra, Indonesia: Pasaman District (0°13′15.38" N; 100°10′13,17" E) and Padang Pariaman District (0°33′16.83" S; 100°12′54.57" E).

In Pasaman district, studies were undertaken in Simpang Alahan Mati (Simpati) sub-district (see Fig. 1), specifically in two *Nagari*, Simpang and Alahan Mati. *Nagari* refers to the village, the smallest administrative subdivision of West Sumatra Province. Simpang and Alahan Mati were selected for this study because they are among the pioneer cocoa cultivating areas in Pasaman District and have the greatest number of cocoa-based agroforestry land uses (BPS Pasaman, 2021). The distance to Padang City, the provincial capital, is approximately 152 km, while the distance to the district capital of Lubuk Sikaping is approximately 20 km. Simpati sub-district has a land area of approximately 49,496 ha. Simpati sub-district has elevation ranging from 100 to 453 m a.s.l with annual average precipitation of 324 mm, and temperatures ranging from 27 to 30 °C. Pasaman district dominated by soils classified as Lithosols and Podzols (BPS Pasaman, 2021).

Two types of cocoa-based AFS were observed in Pasaman: Multi-strata cocoa-based AFS (CM) and cocoa

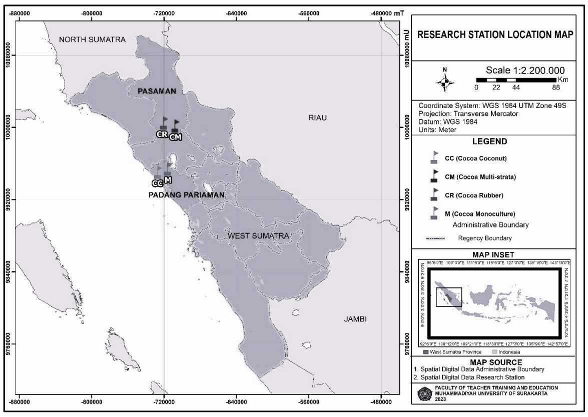

Fig. 1: *Research location in West Sumatra, Indonesia: Pasaman District: CM (Cocoa Multi-strata) and CR (Cocoa Rubber) in sub-district of Simpang Alahan Mati; Padang Pariaman CC (Cocoa Coconut) and M (Cocoa Monoculture) in sub-district of Sungai Geringging*

grown under shade of rubber (*Hevea brasiliensis*) (CR). The multi-strata cocoa-based AFS is a multi-layered AFS, composed of timber tree species as the emergent layer such as 'surian' (*Toona sureni* (Blume) Merr.) and 'bayua' (*Pterospermum javanicum* Jungh.) and non-timber shade trees as mid-layer such as 'jengkol' (*Archidendron pauciflorum* (Benth.) I.C.Nielsen), 'pinang' (*Areca catechu* L.), 'durian' (*Durio zibethinus* Rumph. ex Murray), 'lansek' (*Lansium Parasiticum* (Osbeck) Sahni & Bennet), and 'candlenut' (*Aleurites moluccanus* (L.) Willd.). Cocoa and other crops occupy the lower layer. The second type of cocoa-based AFS commonly found in Pasaman District is cocoa planted under the shade of rubber trees (CR). Pasaman District had developed rubber plantations during the rise of rubber prices in the 1980s, and planted cocoa underneath the aforementioned rubber trees during the subsequent drop in rubber prices in the 1990s. The afore-mentioned cocoa agroforestry systems are managed with limited cost and maintenance.

In Padang Pariaman District, studies were undertaken in Sungai Geringging sub-district (see Fig. 1). Padang Pariaman District has an area of roughly 9,935 ha, and its elevation is 25 m a.s.l. Temperatures range from 24.4 °C–25.7 °C, and annual precipitation averages 368.4 mm. Sungai Geringging is located in a mountainous region with rugged terrain. The three soil types found in this region are alluvial, podzolic, and peat. The cocoa-based AFS observed in Padang Pariaman was characterised as cocoa cultivated in combination with coconut trees (CC). In this particular region, the cultivation of cocoa without shade, commonly referred to as cocoa monoculture (M), has also been practiced. Consequently, we collected data from these plantations for the purpose of comparison. This district had the most advanced agricultural management, as local farmers formed associations that were officially recognised and supported by the government, and operated large privately owned corporate plantations using either monoculture or AFS practices.

2.2 Data collection

This study employed a financial analysis approach to investigate the trade-off between carbon storage, which has potential value in carbon markets, and the productivity of cocoa agroforestry systems (AFS) themselves. The research involved comparing the primary cocoa bean production and the additional benefits derived from shade plants (represented as benefit model) against the associated budgetary expenditures (represented as cost model). This research employed two distinct kind of data, specifically primary data and secondary data. The primary data was collected through interviews utilising a questionnaire and direct monitoring methods of cocoa fruit harvest. To collect financial information pertaining to infrastructure and labour expenditures, as well as co-benefit data associated with the harvesting of cocoa-shade plants, interviews were performed employing a structured questionnaire. A series of interviews were carried out with a total of 62 farmers who are affiliated with two distinct cocoa farmer associations (CM and CR) in Simpati District, along with an additional 61 farmers from Sungai Geringging District representing CC and monoculture practices. The individuals selected for the interviews were farmers who have been cultivating privately owned land with cocoa as the main crop for at least three years. The interview data collected in each sub-district was then verified through focal group discussions. The data was additionally corroborated by consultation with the agricultural extension center affiliated with the local government.

Methods of direct harvesting were used to assess primary cocoa bean production. We randomly selected ten trees from each cocoa-growing region to represent the cocoa-based AFS. We monitored the fruit production of each of the ten trees for one year. In order to estimate the dry bean weight, ten pieces of cocoa fruit were sun-dried until they attained a consistent weight. To evaluate the additional benefits of shade plants, farmers were surveyed and asked to complete a monthly harvest record questionnaire (Rajab *et al.*, 2016).

Infrastructure and labour costs were used to calculate the costs of implementiong agroforestry. To gather this information, interviews were conducted with members of the farmers' association who are currently actively developing AFS. A financial analysis was performed to determine the net added value that AFS provides to both the individual and the general farmers' association. The methodology of this study compared Agroforestry Business as Usual (aBAU), a financial forecast for the case agroforestry activities are carried out as usual without any benefits from carbon storage services, with a system where agroforestry activities are incorporated in the voluntary carbon market (VCM).

The secondary data consisted of information regarding various plant species found in the studied AFS. This data has been collected and analysed by Santhyami *et al.* in 2018, specifically focusing on the composition of species found in the AFS systems (table 1) and estimating their carbon biomass (table 2) (Santhyami *et al.* 2018, 2020).

Table 1: *Composition of cocoa based agroforestry systems (AFS) in West Sumatra (after Santhyami et al., 2020)*

AFS type	*No*	*Species*	*IV (%)**
Cocoa-Rubber (CR)	1	*Hevea brasiliensis*	129.75
	2	*Tectona grandis*	10.45
	3	*Pterospermum javanicum*	7.88
	4	*Durio zibethinus*	6.53
	5	*Lansium parasiticum*	6.41
	6	*Musa spp.*	7.47
	7	*Theobroma cocoa*	131.51
Total			300
Cocoa Multistrata (CM)	1	*Annona muricata*	3.82
	2	*Areca catechu*	43.44
	3	*Aleurites moluccanus*	48.21
	4	*Hevea brasiliensis*	82.26
	5	*Archidendron pauciflorum*	6.98
	6	*Durio zibethinus*	24.90
	7	*Lansium parasiticum*	8.73
	8	*Theobroma cacao*	81.65
Total			300
Cocoa Coconut (CC)	1	*Areca catechu*	50.47
	2	*Cocos nucifera*	93.70
	3	*Archidendron pauciflorum*	3.79
	4	*Parkia speciosa*	8.12
	5	*Toona sureni*	11.29
	6	*Myristica fragrans*	4.12
	7	*Syzygium aromaticum*	13.01
	8	*Durio zibethinus*	3.99
	9	*Musa spp.*	34.82
	10	*Theobroma cacao*	76.68
Total			300

*IV: Importance value, the sum of relative density (RD), relative frequency (FR) and relative dominance (RDo).

2.3 *Data analysis*

The analysis of above ground carbon stock used in financial analysis was based on Santhyami *et al.* (2018). All financial data was collected in Indonesian Rupiah (RP) and converted to US Dolar (USD) using a conversion rate of RP 14.168 to 1 USD. The financial analysis used cost and benefit model. The cost model for cocoa farming can be separated into two categories: the cost of nfrastructure and the cost of labour. On agroforestry practice, farmers operate plant nurseries on an independent basis. As in the financial analysis of monocultures, the costs of plant seeds for agroforestry practices were included in the financial analysis based on interviews with local seed distributors in order to determine the opportunity costs associated with operating nurseries. Labour costs include: land preparation, planting, fertilisation, maintenance, and harvesting expenses.

Table 2: *Carbon storage of cocoa based agroforestry systems (AFS) and monoculture in West Sumatra, Indonesia (after Santhyami et al., 2018)*

		Carbon biomass		
Type of land use	*District*	Total ($Mg\ C\ ha^{-1}$)	*Cocoa* (%)	*N-Cocoa** (%)
CM	Pasaman	99.23	6.89	93.11
CR	Pasaman	61.89	13.44	86.56
CC	Padang Pariaman	103.42	3.81	96.19
M	Padang Pariaman	10	100	0

*non-cocoa - shade plants; CM: cocoa-multistrata, CR: cocoa-rubber, CC: cocoa-coconut, M: cocoa monoculture

In West Sumatra, the primary distinction between monoculture and cocoa-based AFS is that labourers in monoculture were compensated with daily wages. In contrast, in the majority of agroforestry systems, farmers cultivate the land with the assistance of family members and without compensation. Daily wages for family members were incorporated into the financial model to account for the opportunity cost incurred by the farmer in relation to other activities. The opportunity cost is considered to equal the regular minimum wage in the two research locations of 5.3 USD per day.

For the benefit model, according to field observations and interviews, cocoa beans are ready for harvest after four years. For the calculation of cocoa yields, specifically, monthly interviews with agroforestry and monoculture farmers and measurements of the dry bean weight of a number of pods were done to determine the average yield by ecosystem category. The anticipated harvest pattern for the following two decades was estimated according to a model created by Obiri *et al.*, (2007).

Throughout the process of financial analysis, the Net Present Value (NPV), Benefit Cost Ratio (BCR) and Payback Period (PP) were analysed. NPV calculates the estimated current value of a future payment by using a discount rate. The NPV represents the current value of the income stream produced by an agroforestry system. In order to determine the viability of the system, a positive or zero NPV is regarded acceptable, while a negative NPV leads to its elimination. The Benefit-Cost Ratio (BCR) is a quantitative measure that compares the present value of the benefit stream to the present value of the cost stream. The profitability of the cocoa agroforestry system is determined by the BCR ratio, which serves as an indicator of the system's financial viability. A BCR ratio more than one signifies a lucrative system, where the accumulated revenue exceeds the incurred costs. Conversely, a BCR ratio less than one indicates an unprofitable cocoa agroforestry system. PP is the amount of time to recover the cost of the initial investment of an agroforestry project. The payback period has been recognised as the predominant financial metric for assessing the economic feasibility of optimised size in comparison to alternative financial indicators. Interest rate used is 10 %.

The formula for each analysis is as follows:

$$NPV = \sum_{t=n}^{t=0} \frac{Bt - Ct}{(1+i)^t} \tag{1}$$

Where NPV = Net Present Value; Bt = Benefit in year t; Ct = Cost in year t; i = interest rate (10 %); t = time period.

$$BCR = \frac{\text{PV Benefit}}{\text{PV Cost}} \tag{2}$$

Where BCR = Benefit Cost Ratio, PV Benefit = the sum of discounted benefits; PV Cost = the sum of discounted costs.

The financial analysis evaluated relevant data covering a span of 20 years, in accordance with the typical duration of forest carbon projects. In the financial analysis, a comparison of two land development schemes is utilised; (1) the Agroforestry Business as Usual (aBAU) scheme is a financial projection made when agroforestry is implemented as usual without any rewards from carbon storage services, and (2) a carbon offset scheme is made when activities are included in the voluntary carbon market (VCM) based on the Chicago climate exchange (CCX) (Current *et al*,. 2010).

With the existence of a carbon trading mechanism, it should be an alternative source of additional income for cocoa agroforestry farmers who have relied on the results and benefits economy, particularly from non-timber products, in the past. However, participation in the voluntary carbon market incurs the transaction costs of the carbon scheme, which farmers must endure as carbon sellers. In the Plan Vivo scheme, one of the VCM-based programs for forests, transaction costs consist of registration and validation fees (issued once for one carbon project), monitoring expenses (incurred annually during the term of the carbon project), and verification fees (issued every five years during carbon project term). According to research conducted by Antoko (2011) and some of the experiences Plan Vivo had with their projects (Plan Vivo, 2008), the total transaction fees that would be charged would not exceed forty percent of the total value of the carbon project.

The calculation of the economic value of carbon in this study uses a transaction fee equal to forty percent of the total carbon value of the project, although it does not rule out the possibility that the cost of transactions may vary between projects. This does not preclude the possibility that transaction costs may vary between projects.

The unit of sale employed in the carbon payment scheme is VER (Voluntary Emission Reduction). A single VER equals one ton of carbon dioxide emissions. This study applies sensitivity analysis based on VER price. The VER price, refer to the average price of carbon for forest and land use projects, was 8 USD Mg CO_2e^{-1} ($CO_2 = C * 3.67$) (Hamrick & Gallant, 2017). During the sensitivity analysis, the carbon price of USD 10 Mg CO_2e^{-1} and USD 12 Mg CO_2e^{-1} was also used in terms of sensitivity comparison.

3 Results

3.1 Cost and benefit model

The general cost-benefit model for four varieties of cocoa-based land removal over twenty years is depicted in Fig. 2. Infrastructure and labor are initial costs associated with all cocoa-based land uses. The majority of costs involve the acquisition of cocoa seedlings, fertilisers, herbicides, machinery, and lathe machines. Cocoa monoculture has the highest initial costs, at nearly 2,000 USD per hectare, compared to half the cost of clearing land for the other three farming methods. Costs associated with infrastructure and facilities vary for cocoa-based development. CR and CM are examples of agroforestry with minimal infrastructure costs and without the use of fertiliser. Likewise, plant nurseries can be independently managed. The distinction is most pronounced in the benefit model. Due to the harvest of bananas, the only shade crop for cocoa, and the harvest of cocoa beans, which begin to produce fruit in the fourth year, monoculture generates high profits in the first five years. The CR and CM varieties did not bear fruit until the fourth or fifth season. In the twentieth year, CR and CC generated revenue from the sale of timber as a co-benefit commodity.

At the early stage of cocoa based land use (0-2 yeas), benefit obtained was 68 % and 5.7 % higher in the monoculture system than CR and CC, while CM has not given benefits in the early stage (Fig 3A). Banana harvests from the first three years of monoculture yield approximately

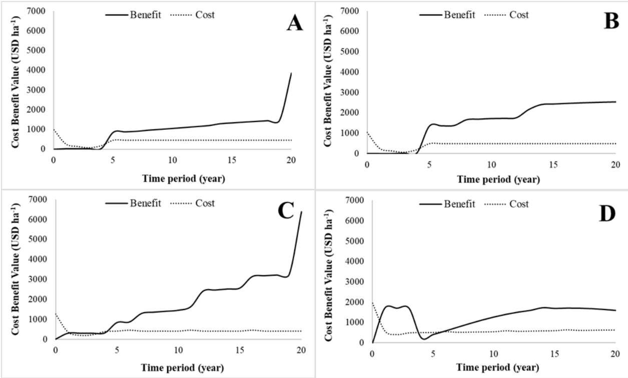

Fig. 2: *Cost and benefit model of cocoa-based AFS and monoculture in West Sumatra: A. CR: cocoa rubber; B. CM: cocoa multi-strata; C. CC: cocoa coconut; D. M: cocoa monoculture.*

1,708.07 USD per hectare annually. Until the third year, the shade plant of choice in cocoa monocultures was banana. Beginning in the fourth year, monoculture farmers begin harvesting cocoa beans. Based on the findings derived from the estimation outcomes of monthly dry cocoa bean production over the course of a year, it has been established that the cultivation of cocoa through monoculture practices yields the maximum quantity of dry cocoa beans, specifically amounting to 908 kg ha^{-1} annually. The cocoa bean production in the CR, CC, and CM regions of AFS was recorded as 280, 223, and 186 kg ha^{-1}, respectively. Prior to the fifth year, neither CR nor CM farmers generated a substantial revenue. During the initial 4-year period, farmers earn between 21.17 USD and 39.80 USD per hectare annually from the harvest of cocoa, soursop, and banana plants. In the first four years of harvesting bananas, farmers in CC might make roughly $300 USD. However, at the final stage of the project (18-20 years), this benefit revenue was 2.6 % greater in CC than monoculture. At total, across all age ranges, CC showed the highest average benefit, 1.4 higher than that of the monoculture systems (Fig 3B). By the end of the 20th year, farmers in CC and CR have increased revenue due to timber harvests. Teak (*Tectona grandis*) and 'bayur' (*Pterospermum javanicum*) were plentiful in CR, while 'surian' (*Toona sureni*) was prevalent in CC. In the 20th year, each CR and CC can earn 2,371.54 USD and 2,978.54 USD per hectare from timber yield output, respectively.

Costs in cocoa monoculture systems were, on average, 138 to 150 % higher than those in cocoa agroforestry systems across all age groups (Fig. 4B). Monoculture has the greatest total capital cost (1,942.93 USD) in the first year of planting land for the 20-year project, which includes labor costs (756.88 USD) and infrastructure expenditures (1,185.84 USD). The monoculture (M) averaged 217 %, 207 %, and 159 % greater than CR, CM, and CC during the

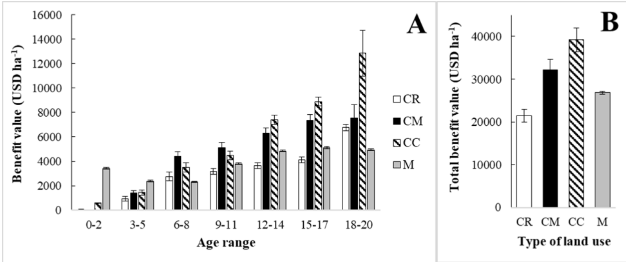

Fig. 3: *Benefit of cocoa based land-use in West Sumatra; A. Benefit per age range; B. Total benefit of 20 years project. CR: cocoa rubber; CM: cocoa multi-strata; CC: cocoa coconut; M: cocoa monoculture.*

early stage (0–2 years), respectively. The majority of cocoa-producing area in West Sumatra already has well-developed infrastructure and facilities. The acquisition of cocoa seeds, fertilisers, herbicides, equipment, and lathe machines accounts for the majority of expenses. In cocoa monoculture practices, cocoa saplings were intercropped with banana trees for the first three years to provide cocoa saplings with shade, subsequently followed by the removal of the banana trees. The overwhelming majority of farmers do not purchase banana saplings, as they are easily obtained from the nearby farmland. Nevertheless, the cost of banana seedlings was included in the financial analysis. This was done based on market interviews with the local distributor of seeds and saplings. In cocoa-based AFS, the cost of infrastructure and facilities varies. CR and CM, for instance, have the most frugal budgeting practices. Neither of these methods required the use of commercial fertiliser.

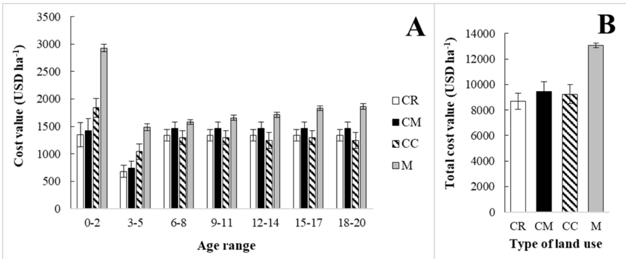

Fig. 4: *Cost of cocoa based land-use in West Sumatra; A. Cost per age range; B. Cost benefit of 20 years project. CR: cocoa rubber; CM: cocoa multi-strata; CC: cocoa coconut; M: cocoa monoculture.*

3.2 *Financial analysis of agroforestry business as usual (aBAU) per ha*

There are distinct benefits to monoculture and cocoa agroforestry, as well as co-benefits, for various land uses. After one year of planting cocoa in monocultures, farmers begin to reap its benefits. After three years of cultivation, the cocoa monoculture farmer can anticipate earning approximately 1,708 USD per hectare per year from the production of bananas. The farmers from CR and CM do not begin to generate significant profits until the fifth year of operation. In the financial analysis calculation based on price data from January to May 2020, which is based on the previously specified cost (budget) and production (benefit) models, an interest rate of 11.73 percent is used. Table 3 compares the NPV, B/C ratio, and Payback Period of various cocoa cultivation techniques.

Table 3: *Financial analysis of agroforestry business as usual (aBAU) per ha.*

Land use type	*NPV (USD)*	*B/C ratio*	*Payback period (year)*
Cocoa monoculture (M)	4,150	2.92	2
Cocoa rubber (CR)	2,423	2.73	7
Cocoa multistrata (CM)	5,617	4.71	6
Cocoa coconut (CC)	6,647	5.80	7

NPV: Net present value; B/C ratio: benefit cost ratio.

Calculations for NPV, B/C ratio, and PP in Table 3 are performed using a cash flow analysis based on the cost and benefit model depicted in Fig. 2. All cocoa agroforestry types compared in this study had a B/C Ratio greater than 1, indicating that all investments are profitable. The cocoa-coconut (CC) has the highest B/C Ratio of 5.80. It also shows the highest NPV of 6,647 USD, making it 15,50 %, 63.55 %, and 37.56 % higher than the CM, CR, and M groups, respectively. Among the four varieties of cocoa-based agriculture, monoculture practices have the quickest return on investment, specifically in the second year. In the Padang Pariaman Regency, the most profitable AFS group is the CC group. After 12 years, coconuts can be harvested, at which point the trees produce 30 coconuts per stem annually.

3.3 *Comparison of financial analysis of AFS with and without a carbon trading scheme*

Table 4 displays the NPV comparison of four types of cocoa based land use without carbon payments (business as usual) and with carbon payment scheme. By joining the carbon payment system through VCM, producers can increase their NPV by 15 to 25 % at a VER price of 8 USD Mg CO_2e^{-1}

4 Discussion

Carbon can be stored better in cocoa-based AFS than in monoculture (Table 2) but monoculture produces 3.2–4.9 times more dry cocoa beans than AFS. Several factors contribute to the high cocoa yield in monocultures. The number of cocoa stalks per hectare was greater under monoculture conditions. The average number of cocoa pods and weight of cocoa seeds per month was greater in monoculture than in AFS, according to monthly harvest data. In monoculture, the presence of fertilisation and maintenance factors (regular pruning twice a year) can increase cocoa production. Fertilisation was performed out routinely by Pariaman farmers every year, while the AFS practice of cocoa in Pasaman was generally not fertilised. In addition to fertilisation factors, a number of cocoa stalks at the AFS in Pasaman exhibited symptoms of fruit decay during field observations. Fruit rot disease is characterised by the presence of blackish-brown spots on cocoa fruit, beginning on the side of the fruit where *Phytophthora palmivora* caused the initial infection. Sometimes, rotten fruit parts turn black and mummify (Drenth and Guest, 2004). This disease is common in cocoa plantations with high levels of shade and humidity. In general, pathogens that cause fruit decay are controlled by reducing humidity in cocoa plantations through pruning, improving water channels, improving garden sanitation, and burying cocoa pods and nfected plant parts (Drenth and Guest, 2004). AFS cocoa is less productive than monoculture cocoa due to the large percentage of shade in AFS and the lack of care and pruning.

The location of the cocoa AFS, which is on the border of a natural forest and far from residential areas, is likely to result in lower garden maintenance than monoculture practices in Pariaman, which are located near farmer settlements. The extent of pest management is also influenced by the location of the garden. Based on interviews with cocoa agroforestry farmers in Pasaman, it was determined that monkey pest attacks are one of the greatest obstacles for producers. To date, Pasaman cocoa producers have only reaped the greatest harvest from cocoa when it coincides with other fruit harvests, allowing them to divert pests from the cocoa plants. Shooting and stalking are the only methods Pasaman farmers use to control monkeys.

The third causal element pertains to the choice of seed factor utilised. In Pariaman, monoculture farmers predominantly engage in the cultivation of cocoa utilizing hybrid seeds. Typically, the seeds employed in this study consist of F1 clones TSH 585 and ICS 60. Hybrid seeds has the inherent benefit of enhanced resistance against fungal infections, so conferring a heightened level of protection. Additionally, the resultant beans exhibit augmented size, thereby leading to an increased weight of cocoa beans. According to Obiri *et al.* (2007), hybrid cocoa has less dependence on extensive shade and demonstrates the ability to achieve larger

Table 4: *Sensitivity analysis of cocoa-based agroforestry cultivation with and without the voluntary carbon market (VCM) scheme*

	Net present value (NPV)						
	without CP	*with CP (USD)*			*percentage increased credited by CP*		
Agroforestry type	*(USD)*	*8 USD*	*10 USD*	*12 USD*	*8 USD*	*10 USD*	*12 USD*
Cocoa monoculture (M)	4,150						
Cocoa rubber (CR)	2,423	3,021	3,171	3,320	24.7	30.9	37.0
Cocoa multistrata (CM)	5,547	6,571	6,809	7,048	18.5	22.8	27.1
Cocoa coconut (CC)	6,647	7,641	7,889	8,137	15.0	18.7	22.4

CP: carbon payments; The price of carbon payments is established at 8 USD Mg CO_2 e^{-1} accompanied by a sensitivity analysis ranging from 10 to 12 USD Mg CO_2 e^{-1}

yields at an earlier stage compared to cocoa derived from conventional seeds. Nonetheless, this approach lacks sustainability due to its correlation with elevated requirements of fertilisers and insecticides for cocoa trees. The presence of less shade is often associated with negative consequences, including heightened vulnerability to insect pests (Entwistle, 1985) and an increased presence of weeds, leading to greater nutritional demands (Ahenkorah *et al.*, 1974).

Cocoa and coconut as intercropping (CC) had the highest carbon sequestered, amounting 103.42 Mg C ha^{-1} (Santhyami *et al.*, 2018). Cocoa and coconut intercropping are a common form of agroforestry in Indonesia and Malaysia (Murniati *et al.*, 2022). This form of agroforestry is also prevalent in Ghana (Osei-Bonsu *et al.*, 2002). According to Mathes (1986), cocoa-coconut intercropping generates the highest relative revenue, second only to cocoa monoculture and surpassing the combination of cocoa and coffee (*Coffea robusta*) and black pepper (*Piper nigrum*).

According to the findings of this study, there is no consistent distance between cocoa and coconut plants; however, it is estimated that one hectare of land contains at least 358 cocoa stalks and 171 coconut stalks. Coconuts, the most important shade plants, can produce an annual average of 5,130 fruits per hectare. According to Purseglove (1976), 2,500 to 7,600 coconuts are collected on average, with a density of 140 to 200 coconut stems per hectare. The optimal density for cocoa and coconut agroforestry in Ivory Coast is between 140 and 200 trees per hectare (Coomans 1974, De-Taffin *et al.*, 1992).

According to Table 3, CC is characterised by the highest NPV value across various types of land development, while simultaneously exhibiting the lowest payback period value. The reason for CC having the highest NPV is due to its inclusion of components that have diverse harvest seasons. During the initial phase of the time period, farmers engaged in the cultivation of bananas as a means of generating cash. During the fourth year of growth, the cocoa plant initiates the production of fruit. Additionally, CC possesses a significant component of clove trees, which holds a considerable market value of approximately 5.3 USD per kilogram. At the conclusion of the designated time frame, farmers receive revenue from the timber component, specifically from the surian (*Toona sureni*) variety. Consequently, the NPV of the CC system exhibits the highest value in comparison to other systems. Nevertheless, several farmers prefer not to utilize the CC option due to its extended term of payback. The coconut component, serving as the primary ingredient with cocoa, is only harvested over a period of twelve years.

It is recommended that the cocoa-coconut group be expanded, as it is superior in terms of carbon storage and leads to higher long-term yields (Panda *et al.*, 2020, Kumar & Kumahu, 2021). This study finds similar results further corroborating previous studies as well as demonstrating the superiority of CC AFS specifically to West Sumatra. One of the primary advantages of incorporating coconut into an agroforestry system is longevity of the production cycle of a single tree, on average up to seventy years; allowing the aforementioned tree to viable and commercially capture carbon for the duration of the production cycle and store carbon in long lived timber products and derivatives. Coconut trees are able to survive in a vast range of climates; optimal growth and yields can only be expected in temperatures ranging from 27 to 29 °C and annual precipitation ranging from 1,250 to 2,500 mm. The combination of cocoa and coconut has several advantages, including the ability to effectively utilise sunlight radiation, strongly bind soil moisture, and resist erosion on sloped terrain.

According to the findings of aBAU's financial analysis, the result reflects the reason why farmers might decide to intensify agriculture and move toward monoculture. The value of the short-term economic benefits of cocoa plantations or monoculture farming is greater than with agroforestry approach. Monoculture yields in West Sumatra are greater than Ghana's reported annual cocoa harvest of 849 kg per hectare (Abdulai *et al.*, 2018), but less than Sulawesi's comparable methods, which yield 2,400 kg per hectare annually (Rajab *et al.* 2016). Monoculture cocoa in West Sumatra produces more beans than any of the other three cocoa-based AFS types, at 3.2, 4.89, and 4.06 times the level of CR, CM, and CC, respectively. The average difference in cocoa bean harvest yields between low shade agroforestry and monoculture was approximately 40 percent, according to Steffan-Dewenter *et al.* (2007).

In short, the farmer gained a relatively short return on investment period for monoculture practices. Farmers can earn a return on their initial investment in two years. For a period of three to four years, bananas can continue to generate income (revenue) for farmers. Bananas are capable of absorbing carbon at a rate of 2.26 kg C/ plant, or 0.98 Mg C/ ha, as determined by a study of numerous Indonesian banana plantations (Danarto & Hapsari, 2015).

Bananas can withstand the damaging effects of environmental exposure. In addition to being determined by genetic variables, it is also affected by associated microbiological factors, especially endophytic bacteria (Rahayu *et al.*, 2021). Bananas are removed after four years because their growth becomes detrimental to cocoa and coincides with the beginning of cocoa plants' reproductive phase (Ediwirman, 2022). Bananas are a type of fruit with a high rate of nutrient absorption. Thorold (1975) demonstrated that *P. palmivora* infections on banana blossoms are contagious and causes an outbreak of fruit rot disease as was demonstrated by bananas that had previously become a common crop on West African cocoa farms. Additionally, banana trees should not be used as cocoa shade trees because they compete with cocoa for nutrients and water, resulting in less-than-satisfactory cocoa yields. It is possible to use banana trees as cocoa shade trees, but it is not recommended (Wood and Lass 1987, Fauzan *et al.* 2103). The second element is research and the development of hybrid cocoa, which, as explained previously, enables cocoa to be grown with minimal shade.

According to Somarriba *et al.* (2103), in order to determine the cocoa-based agroforestry design that provides the optimal trade-off between high harvest value and high carbon stock, it is necessary to consider a number of primary factors. The question to be answered is whether it is possible to develop cocoa farms with high carbon stocks from cocoa and shade crops, while simultaneously producing high yields from cocoa and shade plants.

Several distinct tendencies can be inferred from the following study's findings: Initial observation is that the maximum yields from cocoa in monocultures tends to decrease as carbon stocks of shade crops levels rise. The multistrata cocoa group (CM) that contained a proportion of plants with the highest shade tolerance produced the lowest cocoa yields. This conclusion is consistent with the results of a study conducted in Ghana. Cocoa intensification provides a gradient in the biomass above ground level between 39–131 Mg ha^{-1}(Wade *et al.*, 2010). This tendency is also corroborated by Somarriba *et al.* (2013), that the cocoa yield decreased non-linearly with an increase of the carbon stock from shade crop, namely through an increase of individual number shade plants.

Second is that the carbon stock of cocoa plants has no effect on shade crop yield. This statement is owing to the average age of cocoa being younger compared to the aforementioned shade plants. The difference in harvest on each cocoa-based AFS will depend on system design, management and climatic and other factors. Third is that crop yields of shade crops in monoculture farming is the lowest, and peaks in AFS with productive shade plants such as coconut in Pariaman and mixed in the multi-strata groups. In West Sumatra, the smallest yield of shade plants is found in cocoa–rubber groups (CR) aside from monoculture ones. This is in line with research by Cotta *et al.* (2008). The economic yield of shade plants decreased in rustic practice (Gama-Rodrigues *et al.*, 2011). Rustic means that the cocoa is planted under a thinned natural forest (Sambuichi, 2002). Rustic canopies are generally a mix of valuable shade types intercropping commercially with non-commercial tree species. Shade levels increase with decreasing crop management intensity.

In a strict economic perspective, cocoa monoculture farming potentially produces higher short-term yields than agroforestry. However, cocoa agroforestry has numerous environmental advantages over monoculture, such as greater carbon sequestration and storage; biodiversity protection in the form of conservation of biological corridors or protection of bird species; watershed protection and soil conservation; etc (CABI, 2007). Financial gains from cocoa commodity sales should not be perceived as the sole source of income for farmers; rather, the emphasis should be on maximising the income per unit of land (Schroth *et al.*, 2004).

By evaluating the carbon-absorbing properties of cocoa-based AFS, specifically in West Sumatra, the strategy of establishing AFS together with VCM under the Plan Vivo scheme shows great potential. At the VER USD 8 scenario in which three types of cocoa-based AFS were included in the VCM, the NPV of cocoa producers can increase by as much as 25 %. At least for a 20-year carbon project of this magnitude, farmers can expect to receive a service fee between USD 60.70 and USD 100.94 per hectare per year.

Not all carbon sequestration projects offer the same value benefits. The distribution of the benefits as mentioned above could feasibly be beyond simple monetary compensation of individual farmers. The uniquely large areas of AFS, often beyond the scope of individual farmers, necessitate the further development of current farmers' unions and cooperatives. These institutions provide essential services such as nursery training, the exploration, and creation of product marketing chains as well as non material benefits such as continuous and long-term monitoring and assistance. Increasing the benefits of carbon storage services will vary significantly depending on, among other factors, the type of program implemented, the type of agroforestry practised, the price of carbon credits supplied, currency exchange rates, and payment procedures.

Comparatively, in Mozambique's Nhambita Community Carbon Project, local farmers received \$242.60 per hectare in cash payments for seven years in exchange for carbon sequestration services (Jindal, 2004). Another example is the 2006 carbon project in Tanzania, which provides an annual payment of \$0.02 per tree for 20 years (Scurrah-Ehrhart, 2006). Farmers continue to have access to garden produce, such as fruit, firewood, and other NTFPs. The duration of most VCM projects utilising the Plan Vivo strategy is twenty years (MEETB, 2009). This means that agroforestry farmers as producers are responsible for the quantity and quality of this agroforestry over twenty years by adhering to the regulations governing agroforestry cultivation and refraining from felling timber trees during the duration of the project. Every nature-based project should be evaluated periodically (Nandini *et al.*, 2017), and preventing leakage is one of the evaluation criteria. In addition to the consequences of not felling wood during the project's duration, farmers must also comply with the requirements of carbon projects.

In reality, in the vast majority of fee-based projects, there is a risk of leakage. The leak is the potential for an increase in greenhouse gas emissions in regions outside the project's boundaries as a result of operations such as afforestation-reforestation (AR) or removed reforestation (Kollmuss *et al.*, 2008). The majority of actual instances of leakage occur when farmers are unable to plant their land with seasonal crops that provide short-term productivity and income for ordinary farmers after AR activities have been completed. To make room for seasonal crops, farmers typically clear new land by cutting down trees located on the project's perimeter. To reduce the amount of crop loss, it is essential to ensure that AFS farmers participating in the VCM initiative have sufficient land to cultivate alternative crops. The majority of cultivated land in West Sumatra is indigenous communal land, divided by the unique matrilineal inheritance system, and managed under the traditional Minangkabau system of land usage. The majority of farmers divide their land into two distinct maintenance categories: rice fields and agroforestry. In general, rice farmers in West Sumatra focus their efforts on allocating labour to work on other people's rice fields during the planting and harvesting seasons, as well as on agroforestry management during the rice growing season. Due to this system, the community can meet its subsistence rice needs while also earning additional income from agroforestry-related activities performed outside the rice fields.

In addition to the VCM program, the management of the cocoa-based AFS may be able to achieve further goals by exploring additional opportunities; such as water storage and biodiversity conservation through habitat improvement and the provision of diverse flora and fauna. Thus, there is a need for additional research on the prospects and numerous other compensation mechanisms made possible by the development of cocoa agroforestry.

5 Conclusion

This research compares cocoa-based AFSs to cocoa monoculture systems in West Sumatra, Indonesia, and reveals the trade-off between carbon stock and land productivity. One of the three cocoa-based AFS evaluated, the cocoa-coconut (CC) group had the highest carbon stock. In contrast, monocultures generate the greatest quantity of cocoa beans. The annual output of beans decreases as the number of individual shade plants per hectare rises. In the Cocoa Multi-strata (CM) group, the lowest cocoa yields are produced by a greater proportion of individual shade plants. Depending on the local climate and terrain, different varieties of AFS thrive in diverse cocoa-growing regions around the world. The CC and CM groups in Padang Pariaman and Pasaman, respectively, provide the best balance of economic and conservation benefits. According to a long-term financial analysis of Business as Usual, the CC group has the highest Net Present Value (NPV) and BCR, while the CR group has the lowest. Of the four cocoa-based agricultural systems, monoculture had the fastest return on investment during the second year. Implementing the VCM as is outlined in the Plan Vivo enables individual farmers to receive additional annual income ranging between 60.70 USD and 100.94 USD per hectare.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

Abdulai, I., Jassogne, L., Graefe, S., Asare, R., Van Asten, P., & LaÈderach, P. (2018). Characterization of cocoa production, income diversification and shade tree management along a climate gradient in Ghana. *PLoS ONE*, 13(4), 1–17. DOI:10.1371/journal.pone.0195777

Afele, J.T., Dawoe, E., Abunyewa, A.A., Afari-Sefa, V., & Asare, R. (2021). Carbon Storage in Cocoa Growing Systems Across Different Agroecological Zones in Ghana. *Pelita Perkebunan*, 37 (1): 32–49.

Ahenkora Y, Akrofi GS, Adri KK. (1974). The end of the cocoa shade and manuring experiments at the Cocoa Research Institute of Ghana. *J Horticult Sci*, 49, 43–51.

Angelsen, A., & Wertz-Kanounnikoff, S. (2010). What are the main issues of the REDD plan and the evaluation criteria? (in Bahasa Indonesia). *In*: Angelsen, A. & S. Atmadja (eds.) 2010. *Melangkah maju dengan REDD: isu, pilihan dan implikasi*. CIFOR. Bogor: hlm.11âĂŞ22.

Antoko, B.S. (2011). The value of the incendiary community forest carbon incentives based on the Voluntary Carbon Market in North Tapanuli Regency (in Bahasa Indonesia). [Thesis]. Magister Studi Ilmu Pengelolaan Hutan. IPB. Bogor

Austin, K., Harris, N., Wijaya, A., Murdiyarso, D., Harvey, T., Stolle, F., & Kasibhatla, P. (2018). A review of land-based greenhouse gas flux estimates in Indonesia. *Environ. Res. Lett. 13*, 055003.

Badan Pusat Statistik (BPS) Pasaman. 2021. *Statistic of Simpang Alahan Mati Subdistrict*. (in Bahasa Indonesia). Available on: https://pasamankab.bps.go.id/publication.html accessed February 14, 2022

Baliton, R. S., Wulandari, C., Landicho, L. D., Cabahug, R. E. D., Paelmo, R. F., Comia, R. A., Visco, R. G., Budiono, P., Herwanti, S., Rusita, R., & Castillo, A. K. S. (2017). Ecological services of agroforestry landscapes in selected watershed areas in the Philippines and Indonesia. *BIOTROPIA - The Southeast Asian Journal of Tropical Biology*, 24(1), 71–84. https://doi.org/10.11598/btb.2017.24.1.621

Batsi, G., Sonwa, D. J., Mangaza, L., Ebuy, J., & Kahindo, J. M. (2020). Biodiversity of the cocoa agroforests of the Bengamisa-Yangambi Forest landscape in the democratic republic of the Congo (DRC). Forests, 11(10), 1096.

CABI. (2007). Working with and for farmers. *GRO Cocoa*. United Kingdom: 1–8 hlm.

Coomans, P. (1974). Planting densities for the coconut palm. *Oleagineux*, 29, (8-9): 409–414.

Cotta, M. Gonçalves, L., de Paiva, H.N., Soares, C.P.B., Virgens-Filho, A., Dea, C., & Valverde, S.R. (2008). Quantificação de biomassa e geração de certificados de emissões reduzidas no consórcio seringueira–cacau. Árvore 32 (6): 969–978.

Current, D., Scheer, K., Harting, J., Zamora, D., & Ulland, L. (2010). *A Landowner's guide to carbon sequestra-tion credits*: *In association with the Common wealth Project*. Minnesota, MN: Regional Sustainable Development Partnership.

Darkwah, W.K., Bismark, O., Maxwell, A., Desmond, K., Danso, K., Oti-Mensah, B., *et al*. (2018). Greenhouse Effect: Greenhouse Gases and Their Impact on Global Warming. *Journal of Scientific Research and Reports*, 17, 1-9.

Daymond, A. J., Prawoto, A., Abdoellah, S., Susilo, A. W., Cryer, N. C., Lahive, F., & Hadley, P. (2020). Variation in Indonesian cocoa farm productivity in relation to management, environmental and edaphic factors. *Experimental Agriculture*, 56(5), 738-751.

De-Taffin, G., Sakra, N., & Pomier, M. (1992). Planting density and mineral nutrition in coconut plantations. *Pleagineux-Paris*, 47(4), 165-170.

Drenth EA, Guest DI. (2004). Diversity and management of Phytopthora in Southeast Asia. *ACIAR Monograph Series*, 114, 7–9.

Ediwirman, E. (2022). The appearance of cocoa clones tolerant to infection *Phytophthora palmivora. Jurnal Agronomi Tanaman Tropika (Juatika)*, 4(2), 184-193.

Entwistle PF. (1985). Insects and cocoa. *In*: Wood GAR, Lass RA (eds) Cocoa. 4th edn. Longman, London and New York, pp 373–383.

Fauzan, A., Lubis, L., & Pinem, M. I. (2103). Keparahan penyakit busuk buah kakao (*Phytophthora palmivora* Butl.) pada beberapa perkebunan kakao rakyat yang berbeda naungan di Kabupaten Langkat. *Jurnal Online Agroekoteknologi*, 1(3), 374–384.

Gama-Rodrigues, E. F., Gama-Rodrigues, A. C., & Nair, P. K. (2011). Soil carbon sequestration in cocoa agroforestry systems: a case study from Bahia, Brazil. In *Carbon sequestration potential of agroforestry systems* (pp. 85-99). Springer, Dordrecht.

Gockowski, J., & Sonwa, D. (2011). Cocoa intensification scenarios and their predicted impact on CO2 emissions, biodiversity conservation, and rural livelihoods in the Guinea rain forest of West Africa. *Environmental Management*, 48, 307–321.

Hamrick, K., & Gallant, M. (2017). *Unlocking potential: State of the voluntary carbon markets 2017*. Forest Trends, Washington.

Jindal, R. (2004). *Measuring the socio-economic impact of carbon sequestration on local communities: An assessment study with specific reference to the Nhambita Pilot Project in Mozambique*. (Unpub.) University of Edinburgh, UK. Available at:www.miombo.uk.org/research.html.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry Systems*, 76, 1–10. https://doi.org/10.1007/s10457-009-9229-7

Kay, S., Rega, C., Moreno, G., Herder, M. Den, Palma, J. H. N., Borek, R., Crous-duran, J., Freese, D., Giannitsopoulos, M., Graves, A., Jäger, M., Lamersdorf, N., Memedemin, D., Mosquera-losada, R., Pantera, A., Luisa, M., Paris, P., Roces-Díaz, J. V, Rolo, V., ... & Herzog, F. (2019). Land Use Policy Agroforestry creates carbon sinks whilst enhancing the environment in agricultural landscapes in Europe. *Land Use Policy, 83* (February), 581–593. https://doi.org/10.1016/j.landusepol.2019.02.025

Kessler, M., Hertel, D., Jungkunst, H. F., Kluge, J., Abrahamczyk, S., Bos, M., Buchori, D., Gerold, G., Gradstein, S. R., Köhler, S., Leuschner, C., Moser, G., Pitopang, R., Saleh, S., Schulze, C. H., Sporn, S. G., Steffan-Dewenter, I., Tjitrosoedirdjo, S. S., & Tscharntke, T. (2012). Can Joint Carbon and Biodiversity Management in Tropical Agroforestry Landscapes Be Optimized? *PLoS ONE, 7*(10), 1–7. https://doi.org/10.1371/journal.pone.0047192

Kollmuss, A., Zink, H., & Polycarp, C. (2008). *Making sense of the voluntary carbon market: a comparison of carbon offset standards*. Stockholm Environment Institute and Tricorona. Stockholm: 1–199 hlm.

Kumar, B.M., & Kunhamu, T.K. (2021). Nature-based solutions in agriculture: A review of the coconut (*Cocos nucifera* L.)-based farming systems in Kerala, "the Land of Coconut Trees. *Nature-Based Solution*, 2, 100012. https://doi.org/10.1016/j.nbsj.2022.100012

Malawi Environmental Endowment Trust Blantyre (MEETB). 2009. *Forest conservation in Nyika National Park and Mkuwazi Forest Reserve, Malawi*. Plan Vivo. Malawi: 1–121 hlm.

Margono, B.A., Potapov, P.V., Turubanova, S., Stolle, F., & Hansen, M. (2014). Primary forest cover loss in Indonesia over 2000–2012. *Natural Climate Change*, 4, 1–6.

Mathes, D.T. (1986). Economics of intercropping coffee, cacao and pepper under coconut. *Coconut Bulletin*, 3(1), 9–11.

Ministry of Environment and Forestry of The Republic of Indonesia (MOEF). 2016. Press release: Implications of carbon trading on post-indonesia commitments. Accessed on 23.05.2022.

Ministry of Environment and Forestry of The Republic of Indonesia (MOEF). (2020a). *Statistics 2020*. (In Bahasa Indonesia) No ISBN : 978-602-8358-98-9 Press release: Accessed on 23.05.2022.

Ministry of Environment and Forestry of The Republic of Indonesia (MOEF). (2020b). *Performance Report 2020*. (In Bahasa Indonesia). Press release: Accessed on 23.05.2022.

Ministry of Environment and Forestry of The Republic of Indonesia (MOEF). (2020c). *Regulation of The Minister Of Environment And Forestry Of The Republic Of Indonesia number p.51/menlhk/setjen/kum.1/6/2016 concerning procedures for the release of convertible production forest area*. (In Bahasa Indonesia). Press release: Accessed on 23.05.2022.

Ministry of Environment and Forestry of The Republic of Indonesia (MOEF). (2020d). *Regulation of The Minister of Environment and Forestry of The Republic of Indonesia number P.16/Menlhk/Setjen/Set.1/8/2020 Strategic Plan 2020-2024*. (In Bahasa Indonesia). Press release. Accessed on 23.05.2022.

Murniati, M., Suharti, S., Yeny, I., & Minarningsih, M. (2022). Cacao-based agroforestry in conservation forest area: farmer participation, main commodities and its contribution to the local production and economy. *Forest and Society*, 6(1), 243-274.

Nandini, R., Kusumandari, A., Gunawan, T., & Sadono, R. (2017). Multidimensional scaling approach to evaluate the level of community forestry sustainability in Babak Watershed, Lombok Island, West Nusa Tenggara. *Forum Geografi*, 31(1), 28-42.

Netter, L., Luedeling, E., & Whitney, C. (2022). Agroforestry and reforestation with the Gold Standard-Decision Analysis of a voluntary carbon offset label. *Mitigation and Adaptation Strategies for Global Change*, 2,17.https://doi.org/10.1007/s11027-021-09992-z

Obiri, B.D., Bright, G.A., McDonald, M.A., Anglaaere, L.C.N., & Cobbina, J. (2007) Financial analysis of shaded cocoa in Ghana. *Agroforest Systems*, 71, 139–149.

Oke, D., & Olatiilu, A. (2011). Carbon storage in agroecosystems: a case study of the cocoa-based agroforestry in Ogbese Forest Reserve, Ekiti State, Nigeria. *J Environ Protect,* 2, 1069-1075

Osei-Bonsu, K., Opoku-Ameyaw, K., Amoah, F.M., & Oppong, F.K. (2002). Cocoa-coconut intercropping in Ghana: agronomic and economic perspectives. *Agroforest Syst*, 55, 1–8.

Panda, N.K., Sarangi, S.K., Das, H.K., & Kar, M.R. (2020). Role of coconut (*Cocos nucifera*) based agroforestry system in coastal Odisha. *Journal of Pharmacognosy and Phytochemistry*, 9(4), 1742-1745

Plan Vivo. 2008. *The Plan Vivo standards* Available at: https://www.planvivo.org/standard-overview accessed on July 12th 2022.

Purseglove, J.W. (1976). *Tropical Crops-Monocotyledons*. 2nd edn. Longman, London.

Rahayu, T., Purwestri, Y.A., Subandiyah, S., & Widianto., D. (2021). Characteristics of endophytic bacteria from Klutuk banana plant (*Musa balbisiana Colla*) as plant growth promoter. *Al-Kauniyah: Jurnal Biologi, 14* (2), 313-324

Rajab, A.Y., Leuschner, C., Barus, H., Tjoa, A., & Hertel, D. (2016). Cacao cultivation under diverse shade tree cover allows high carbon storage and sequestration without yield losses. PLoS ONE 11(2): e0149949. https://doi.org/10.1371/journal.pone.0149949

Rosalia, S., Yonariza, Y., & Syahrawati, M. (2022). Effect of farmer's behaviour in cocoa management on insect diversity in Salayo Cocoa Plantation, West Sumatra, Indonesia. *Biodiversitas Journal of Biological Diversity*, 23(10), 5064-5073

Roziaty, E., & Pristiwi, Y. (2020). Species diversity in agroforestry systems in Surajaya Village, Pemalang District, Pemalang Regency, Central Java. *Bioeksperimen*, 6(2), 76–88.

Sambuichi, R.H.S. (2002). Phytosociology and diversity of tree species in cabruca (Atlantic forest thinned over cocoa plantation) in the southern region of Bahia, Brazil (in Portuguese). *Acta Bot. Brasil*, 16 (1), 89–101.

Santhyami, Basukriadi, A., Patria, M. P., & Abdulhadi, R. (2020). Tree community composition and structure of cacao (*Theobroma cacao* L.) based agroforestry in West Sumatra, Indonesia. *Bioeksperimen*, 6(1), 54–55.

Santhyami, Basukriadi, A., Patria, M.P., & Abdulhadi, R. (2018). The comparison of aboveground C-stock between cacao-based agroforestry system and cacao monoculture practice in West Sumatra, Indonesia. *Biodiversitas, 19*(2), 472–479. https://doi.org/10.13057/biodiv/d190214

Schroth, G., & Harvey, C. A. (2007). Biodiversity conservation in cocoa production landscapes: an overview. *Biodiversity and Conservation*, 16, 2237-2244.

Schroth, G., Bede, L. C., Paiva, A. O., Cassano, C. R., Amorim, A. M., Faria, D., Mariano-neto, E., Martini, A. M. Z., Sambuichi, R. H. R., & Lôbo, R. N. (2015). Contribution of agroforests to landscape carbon storage. *Mitig Adapt Strateg Glob Change, 20*, 1175–1190. https://doi.org/10.1007/s11027-013-9530-7

Schroth, G., Harvey, C. A., & Vincent, G. (2004). Complex agroforests: their structure, diversity, and potential role in landscape conservation. *Agroforestry and biodiversity conservation in tropical landscapes*. Island Press, Washington, DC, 227-260.

Scurrah-Ehrhart, C. (2006). *Tanzania inventory of payments for ecosystem services.* Forests Trends, Washington DC.

Sefriadi, H., Villano, R., Fleming, E., & Patrick, I. (2013). Production constraints and their causes in the cacao Industry in West Sumatra: From the farmers' perspective. *International Journal of Agricultural Management*, 3(1), 30-42.

Smiley, G. L., & Kroschel, J. (2008). Temporal change in carbon stocks of cocoa–gliricidia agroforests in Central Sulawesi, Indonesia. *Agroforestry Systems*, 73, 219-231.

Somarriba, E., Cerda, R., Orozco, L., Cifuentes, M., Davila, H., Espina, T., Mavisoy, H., Ávila, G., Alvarado, E., Poveda, V., Astorga, C., Say, E., & Deheuvels, O. (2013). Carbon stocks and cocoa yields in agroforestry systems of Central America. *Agric Ecosyst Environ, 173*, 46–57.

Steffan-Dewenter, I., Kessler, M., Barkmann, J., Bos, M.M., Buchori, D., & Erasmi, S. (2007). Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. *Proceedings of the National Academy of Sciences USA*, 104(12), 4973–4978.

Thorold, C.A. (1975). *Diseases of cocoa*. Clarendon Press. Oxford.

Wade, A.S.I., Asase, A., Hadley, P., Mason, J., Ofori-Frimpong, K., Preece, D., Spring, N., & Norris, K. (2010). Management strategies for maximising carbon storage and tree species diversity in cocoa-growing landscapes. *Agricultural Ecosystem Environmental*, 138, 324–334.

Wood, G.A.R., & Lass, R.A. (1987). *Cocoa*. John Wiley Inc. New York.