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Can carbon payments improve profitability of traditional conventional and organic cocoa agroforests? A case study in the Eastern Region of Ghana

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Abstract This study investigates the carbon (C) sequestration of traditional cocoa agroforestry systems in the Eastern Region of Ghana and the theoretical impact of CO_2 emission rights trading on their profitability. The study was conducted in four villages of Suhum Municipality, two each with either conventional or organic cocoa cultivation systems. Profitability was calculated using net present value of net cash-flow (NPV), benefit cost ratio (BCR), and modified internal rate of return (MIRR). Carbon revenues were calculated using CO_2 emission trading rights prices ranging from 7.5 € $t_{CO2eq.}{}^{-1}$ (average EU trading price) to 42 € $t_{CO2eq.}{}^{-1}$(estimated social cost of CO_2 release). We tested the sensitivity of profitability indicators with three scenarios: 300% increase in interest rates, 20% yield reduction, and 10% increase in cost. NPV without CO_2 payment for conventional agroforest was 20% higher than that of organic agroforest. Contrarily, BCR for the organic system was 30% larger than for the conventional counterpart. Profitability indicators for both systems were most sensitive to the 300% interest rate. The average C sequestered was 153 ± 13 t ha^{-1} whereby soil contributed the largest fraction with an average of 88 ± 11 t ha−1. Total C sequestered in the organic system was 30% higher than in the conventional system. In conclusion, CO_2 payments can improve the attractiveness of organic cocoa cultivation for farmers, although the paid price must be oriented to the estimated social costs caused by CO_2 release rather than the currently used trading price in the EU.

Keywords Carbon trading · Climate change · Ecosystem service · Land use systems · Organic agroforestry · Sustainability

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Introduction

Currently, global temperature is 1 °C above pre-industrial levels and is projected to increase to 1.5 °C between 2030 and 2050 (IPCC 2018). To slow down global warming, initiatives such as the Clean Development Mechanism (CDM) in the Kyoto Accord have been developed. The CDM enables companies in developed countries to compensate their carbon (C) emissions as a cost-effective mitigation strategy by financing forestry and agroforestry projects in developing countries (Ringius 2002). In the same vein, C markets were established, where farmers can receive monetary compensation for the C stocks sequestered on their land (Tipper 2002; Seeberg-Elverfeldt et al. 2009). This rationale led

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to the recognition of agroforestry systems as a land use with climate mitigation effects in the Kyoto Accord with the implication that agroforesters can benefit financially from their land use ecosystem services (Takimoto et al. 2008; Walde et al. 2020; Goncalves et al. 2021).

Developing countries like Ghana may utilize this opportunity to reduce poverty and improve the welfare and livelihoods of their small-scale farming communities. One effective strategy to execute this task is by promoting traditional cocoa agroforestry systems (TCAFS) because Ghana is a leading cocoa (*Theobroma cacao* L.) producer with an estimated 1.9 million hectares of production area, employing approximately 800,000 farmers (Sulaiman and Boachie-Danquah 2017). About 9% of the country´s GDP and one third of its export earnings totaling over US $ 1.5 billion come from the cocoa sector (Sulaiman and Boachie-Danquah 2017). Traditionally cocoa is grown together with other food crops under sparse forest tree shade resulting in a system mimicking a forest with multi canopy strata (Asase & Tetteh 2010; Sonwa et al. 2017). Farmers who practice TCAFS are motivated because it allows them to have a regular income (Obiri et al. 2007; Nunoo and Owusu 2017), to ensure food security (Bandanaa et al. 2016), and to improve soil fertility (Wartenberg et al. 2018). However, these systems also sequester C (Asase and Tetteh 2016) and maintain biodiversity (Asigbaase et al. 2019). Hence, conflicts originating from ecosystem service provisions on one part and economic interest on the other are reduced yielding a win–win situation.

In recent years many of the complex TCAFS across cocoa growing regions in Ghana are transformed to monocultures (Ruf 2011). In the Eastern Region of Ghana, drastic reduction of shade tree density and increased inputs such as fertilizer, herbicides, pesticides and fungicides use in TCAFS have increased cocoa yield by 45% (Wade et al. 2010). In the absence of any economic incentive to keep TCAFS alive, such yield increases induce farmers to intensify their farms. However, these increases in cocoa yields may be short lived as observed in the Ashanti (Obiri et al. 2007) and Western (Nunoo and Owusu 2017) regions of the country where 12 to 16 years after monoculture establishment cocoa yields dropped, whilst TCAFS remained productive.

In 2005, organic cocoa certification was introduced in the Suhum Municipality, Eastern Region of Ghana (Glin et al. 2015). Prior to this certification, some villages in the municipality have practiced organic cocoa management for about two decades because they were convinced it sustains their health, plants, and soil productivity (Glin et al. 2015). Because organic certification promotes the use of traditional crop varieties, no chemical inputs, complex agroforestry systems and premium payments on the sale of cocoa beans (Naturland 2014), about 5000 TCAFS farmers in Suhum transitioned from conventional to organic production (Yayra Glover Limited 2021). Such organic TCAFS have been observed to sequester amounts of soil C similar to forests, given high litter deposition (Gama-Rodrigues et al. 2010).

Generally, studies comparing C stocks in organic and conventional traditional agroforests are inconclusive. Whereas Häger (2012) observed that organic coffee agroforests had higher C sequestered than their conventional counterparts, Niether et al. (2019) and Schneidewind et al. (2019) found no difference in cocoa agroforestry systems. Within West Africa such comparisons are scarce because organic certification just started gaining grounds. In addition, data on financial profitability of conventional and organic cocoa production systems are limited and have never been collected under the theoretical implementation of C payments. To fill this knowledge gap, the present study sought to (a) assess the financial profitability and the response of this profitability to adverse production constraints in conventional and organic cocoa agroforestry systems in the Eastern Region of Ghana; (b) estimate the C stocks of organic and conventional traditional cocoa agroforests; and (c) assess the effects of C payments on the economic profitability and its role in reducing the effect of adverse production constraints on profitability in cocoa agroforestry.

Materials and methods

Description of study area

Our study was conducted in Suhum Municipality (6°2′3.84″N and 0°27′8.64″W; mean altitude 450 m a.s.l) in the Eastern Region of Ghana (Fig. 1), West Africa, 60 km northwest of Accra, the country’s capital. The primary natural vegetation is

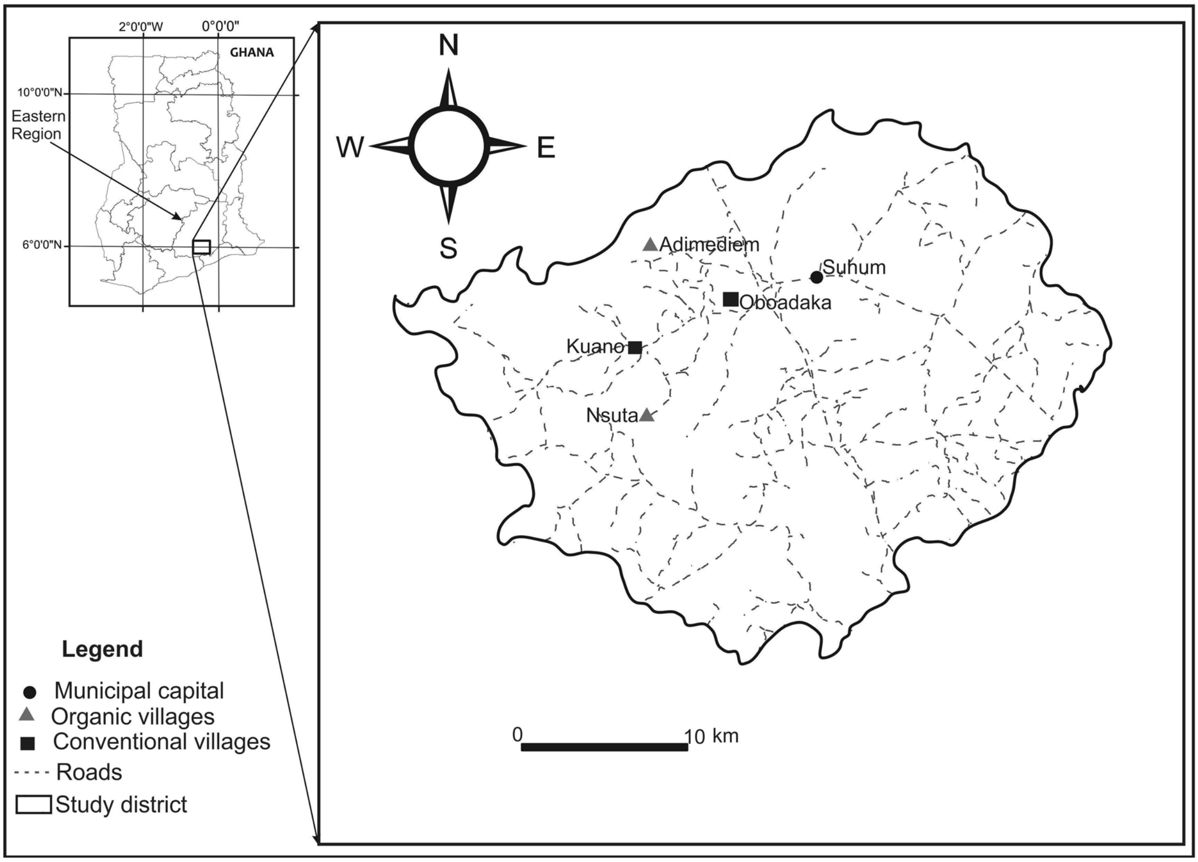

Fig. 1 Map of Ghana on the left showing the study area in the Eastern Region with the four selected cocoa growing villages and the municipal capital

classified as semi-deciduous forest, however, human encroachment has reduced it to secondary forests and regrowth thickets (MOFA 2017). The twelve-years monthly average temperature in Suhum ranges from 20.5 °C to 37.2 °C with the hottest months between January and April (World Weather Online 2021). Annual rainfall ranges from 1270 to 1651 mm with the major rainy season occurring between April and July and a minor rainy season between September and November (MOFA 2017). Suhum Municipality was chosen for this study as it is among the pioneer cocoa growing areas in Ghana and also has the largest number of organic cocoa farmers (Djokoto et al. 2016). The area is predominated by Ferric Lixisols and Haplic Lixisols (IUSS Working Group WRB 2015).

Experimental design

We used a nested (hierarchical) design for this study. One conventional and one organic village was nested within each of the two dominant soil types resulting in a total of four villages. The two conventional cocoa villages Oboadeka (Ferric Lixisol) and Kuano (Haplic Lixisol), named as Con 1 and Con 2, respectively. Similarly, two organic cocoa villages Nsuta (Haplic Lixisol) and Adimediem (Ferric Lixisol), were named as Org 1 and Org 2, respectively. Selected organic villages were among the villages having long term organic cocoa agroforestry systems. Within each of these villages, 50 farms were selected out of 300 farms. Age of cocoa plantations, categorized into juvenile (1–5 years), young (6–15 years), matured (16–30 years) and old (31–50 years), was nested into the four villages.

Description of production systems

All farmers in the study used a mixture of hybrids (improved cultivars) and Amazonian cocoa varieties (old cultivars). The main dichotomy of the two production systems lies in weed and pest control as well as fertilization. Organic farmers controlled weeds strictly by slashing, whereas conventional farmers used both slashing and herbicides with Glyphosate as active ingredient (Round up™, Sunphosate™, Sarosate™ and Kondem™). Mirids or Capsids, *Distantiella theobroma* (Dist.) were controlled in organic farms using Agropy 5EW™ with pyrethrin, a natural organic insecticide, as the active ingredient. On the other hand, conventional farmers controlled mirids by using Akate Master™, Confidor™ and Actara™ with the active ingredients Bifenthrin, Imidacloprid and Thiamethoxam, respectively. At the time of this study, organic farmers did not apply any form of fertilizers. However, two years earlier farmers acknowledged that Yayra Glover Limited (only licensed organic cocoa beans buyer in Ghana) supplied them with 50 kg Elite Organic Fertilizer™ (NPK 3–4–4 + 9 Ca + 1 Mg + 0.04 B + 0.08 Zn + organic matter), corresponding to fertilizer application rates of 14 to 124 kg ha^{-1} (Agbotui unpublished data) depending on farm size and assuming even distribution across the plantations. However, some farmers stated that they did not use this fertilizer at all during this time, whereby the recommended application rate of Elite Organic Fertilizer is 800 kg ha^{-1} yr^{-1} (CHED and WCF 2016). Conventional farmers used Asaase Wura™ (Yara, Ghana) inorganic fertilizer (NPK 0–22–8 + 9 CaO + 7 S + 6 MgO, whereby application rates are 50% of the recommended rate of 300 kg ha^{-1} yr^{-1} by Ghana Cocoa Board (COCOBOD personal communication).

Data collection and analysis

Socioeconomic characteristics and financial profitability assessment

In total 200 farmers were interviewed with closed and open-ended questionnaires to obtain data on farmer and farm characteristics such as the age of plantation, size and cash outflows and inflows. In each village all information given by individual farmers was cross checked during focal group meetings to verify any discrepancy given by farmers during the survey process. Furthermore, data was verified with Yayra Glover Limited, Cocoa Life coordinators, and COCOBOD district officers. Cost and revenue were estimated on a hectare basis as € ha^{-1} based on farm gate prices of June 2019 (1 € = 6.14 Gh ₵). The cash outflows were differentiated into material and labor costs. Material costs consist of money spent on the purchase of materials necessary for cocoa production such as farm tools, cocoa and shade tree seedlings, edible fruits trees and food crops planting materials as well as chemical inputs. Labor costs comprised labor requirement of cocoa production such for land clearing, cocoa and food crops planting, cultural practices and harvesting. Basic land rent amounted to 16.73 € ha^{-1}, because most farmers were sharecroppers. Cash inflow included revenue from the sale of cocoa beans and food crops as well as a premium. Revenues from cocoa beans were calculated by multiplying the number of harvested bags (64 kg) with the price of 79.5 € bag^{-1} as paid by COCOBOD. Revenue from food crops was determined by asking the farmers the amount they accrued from the sale of each food crops from their cocoa farm. This approach was chosen because food crops in the study area are sold based on bargaining not on set prices per weight. For organic farmers, a premium of 7.5 € bag^{-1} was paid by Yayra Glover Limited.

Data from the two villages with the same production system were combined for profitability assessment, because in some conventional and organic villages there were no juvenile cocoa agroforests existent. Simple net cash flow was determined by subtracting gross cost from gross revenue. Net present value of net cash flow (NPV), benefit cost ratio (BCR) and modified internal rate of return (MIRR) were used as profitability indicators. MIRR was used instead of internal rate of return (IRR) because for agricultural projects where periodic cash flows are generated between the start and end of the project, IRR tends to overestimate profitability (Kierulff 2008). To determine the present value of future cash streams, a discount rate of 8% was employed, which is the interest rate given to farmers by the Ghana Export–Import Bank (GEXIM). It was set up by the Ghana Export–Import Bank Act 2016 (Act 911) to support the Government of Ghana´s quest for a feasible and sustainable export led economy (GEXIM Bank 2000). Average revenue and cost of each age category was then used during the discounting process. We assumed a production period of 50 years since this was the maximum age of plantations observed in the study area. At the age of 50 years it is assumed that the cocoa trees are cut and replanted. NPV refers to the net present value of revenue after discounting a stream of revenue and cost to the present year (Eq. 1). A production system is deemed economically viable, when the NPV is greater than zero. BCR is the ratio of the present worth of revenue stream to the present worth of cost stream (Eq. 2). It is the rate of return per unit cost, which is considered profitable at BCR greater to one. MIRR is the discount rate, which makes NPV equal to zero (Eq. 3). The decision criterion is that the land use MIRR is greater than the interest rate.

$$\text{NPV} = \sum_{t=1}^{n} \frac{R_t - C_t}{(1+r)^t} \tag{1}$$

$$\text{BCR} = \sum_{t=1}^{n} \frac{R_t}{(1+r)^t} \div \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} \tag{2}$$

$$\text{MIRR} = \sqrt[t]{\frac{(R \times r)}{(C \times f)}} - 1 \tag{3}$$

where R is revenue, C is cost, r is discount rate, f is finance cost and t is time in years, each.

The financial cost comprises only the discount rate because GEXIM does not charge farmers with additional costs as it is a government sponsored bank. To assess the sensitivity of the production systems, where farmers' livelihoods mostly relied on cocoa production, the profitability indices were rerun under three different scenarios:

(a) A 300% increase in interest rate from 8 to 24%, which was the average interest rate in 2016 (Bank of Ghana 2021).
(b) A 20% reduction in yield due to prolonged drought, which is a realistic scenario for rainfed cocoa cultivation in Ghana.
(c) A 10% increase in cost due to increases in prices for imported agrochemical (currency depreciation) and labor costs (labor scarcity because of migration of young people from villages to urban centers).

Estimation of C stocks

Carbon stocks were determined on 40 farms (10 from each village) selected from the 200 interviewed farmers. In this regard we considered the C stocks in above and below ground biomass of cocoa and shade trees, standing litter (litter on soil surface), and soil at a depth of 30 cm. To estimate C sequestered, a biomass inventory was conducted within a quadrat of 25 m × 25 m in each farm. Within this area, all shade trees were counted, and diameter measured at breast height (DBH; 1.30 m) according to Hairiah et al. (2010). Due to early bifurcation of cocoa trees, diameter was also measured at 30 cm height. Standing litter was collected in a zig-zag manner diagonally through the 25 m × 25 m quadrat at 10 different locations using a 50 cm × 50 cm quadrat. Standing litter was oven dried at 60 °C until constant weight and ground for C determination. At five locations where standing litter was collected, soil samples were taken at depths of 0–30 cm. Samples collected from the same farm were bulked, air dried, sieved and ball milled for C and N analysis. Carbon and N in both soil and standing litter were measured using the Vario Max CN analyzer (Elementar GmbH, Hanau, Germany). Soil organic carbon (SOC) was calculated as the difference between total C and carbonate-C. Carbonate concentration was measured by adding 10% HCl to the soil with emanating gas measured volumetrically (Loeppert and Suarez 1996). Bulk density was measured with metal cylinders with an inner diameter of 3 cm from which contents were oven dried at 105 °C until constant weight was attained. The soil dry weight was then divided by the inner volume of the metal cylinder.

Table 1 Allometric equations used in estimating C stocks in cocoa agroforestry systems of Suhum Municipality, Eastern Region of Ghana, 2019

Group/Species	Equation	Source
Cocoa	$Y = 10^{(1.625 + 2.63 \times \log(D_{(30)})}$	Andrade et al. (2008)
Forest	$Y = 0.30 + DBH^{(2.31)}$	Henry et al. (2010)
Fruit trees	$Y = 10^{(-1.11 + 2.64 \times \log(DBH))}$	Andrade et al. (2008)
Musa spp.	$Y = 0.0303 \times DBH^{(2.1345)}$	Hairiah et al. (2010)
Gliricidia sepium	$Y = -70.172 + 11.5353 \times DBH$	Anglaaere (2005)
Citrus spp.	$Y = -6.64 + 0.279 \times BA + 0.000514 \times BA^2$	Schroth et al. (2002)
BGB	$AGB = \exp^{(-1.085 + 0.926 \times \ln(AGB))}$	Cairns et al. (1997)
SOC	SOC × depth × bulk density	
Standing litter	Standing litter C × dry weight	

Y: =aboveground biomass in kg tree^{-1}, BGB: belowground biomass, $D_{(30)}$: diameter in cm measured at 30 cm above ground, DBH: stem diameter at breast height (1.3 m) in cm, BA: basal area in cm^2 and SOC: soil organic carbon

Basal area of shade trees per hectare was estimated using $\frac{(\pi \times d^2)}{4}$, where d is the diameter at 1.30 m height. The density and basal area of fruit and timber trees were summed up to constitute total shade tree density and basal area, respectively. Total biomass was estimated for all trees using general allometric equations developed for similar ecological zones (Table 1). Above ground biomass for forest shade trees was estimated using an allometric equation developed for Ghanaian forest trees (Henry et al. 2010) which has been previously used for C estimation in cocoa agroforests in Ghana (Asase and Tetteh 2016). All belowground biomass was estimated by an equation developed by Cairns et al. (1997) using forest trees from 25 countries across 6 continents. By multiplying both aboveground and belowground biomass with 0.5, C content was estimated in cocoa and shade trees (Albrecht and Kandji 2003). The potential CO_2 emission prevented by each village was estimated by multiplying total C stocks with 3.64 which is the ratio of molecular weight of CO_2 (44 gmol^{-1}) to C (12 gmol^{-1}) (Atangana et al. 2014).

Economic profitability

We made a hypothetical case of how profitability of these traditional cocoa agroforests could be improved using CO_2 sequestered in each production system as a revenue source. To this end we calculated the annual C accumulation rate by dividing the average total C sequestered in each production system with their average age of plantation (Somarriba et al. 2013). Annual C accumulation rate for each production system was multiplied with 3.64 converting them to their CO_2 equivalent. The assumed revenue from CO_2 was determined by multiplying the annual CO_2 accumulation rate with the average prices of 7.5 € t^{-1} (average EU trading price; Knopf et al. 2014) and 42 € t^{-1} (estimated social cost of CO_2 release; United States Government 2021). The low price is the average price of CO_2 as traded in the EU Emission Trading System (ETS). This scheme allows industries who emit CO_2 below their allowed cap to sell their extra allowance to large emitters. High price is the average monetary value of net harm to society, when a ton of CO_2 is released into the atmosphere estimated by a model of the United States Government (2021) using different discount rates. Assumptions used in the model were global average temperature response to increased atmospheric CO_2, future population, economic and greenhouse gas emissions growth. Profitability indicators of these cocoa production systems and their sensitivity after addition of these assumed CO_2 revenues were recalculated.

Statistical analysis

We fitted a nested ANOVA using a mixed effect model to analyze socioeconomic and biophysical characteristics and C sequestration differences between the production systems using the nlme package in R (Pinheiro et al. 2022). Production systems were considered as fixed effects and soil types as random effects. Pearson correlation was computed

Table 2 Socioeconomic characteristics of conventional and organic cocoa agroforests in Suhum Municipality, Eastern Region of Ghana, 2019

Socioeconomic characteristics	Unit	Conventional	Organic	Overall SEM	*p* value
Formal education	years	8.9	8.8	0.4	0.92
Farmer age	years	53.3	52.1	1.3	0.53
Experience in cocoa farming	years	21.6	22.2	1.3	0.55
Size of household		6.7	5.3	0.3	0.02
Age of plantation	years	21.8	22.2	1.1	0.48
Farm size	ha	2.8	1.9	0.2	0.02
Cocoa yield	kg ha^{-1}	352.4	353.7	19.6	0.32
Gender					
Male	%	92	91		
Female	%	8	9		

SEM denotes the overall standard error of the mean

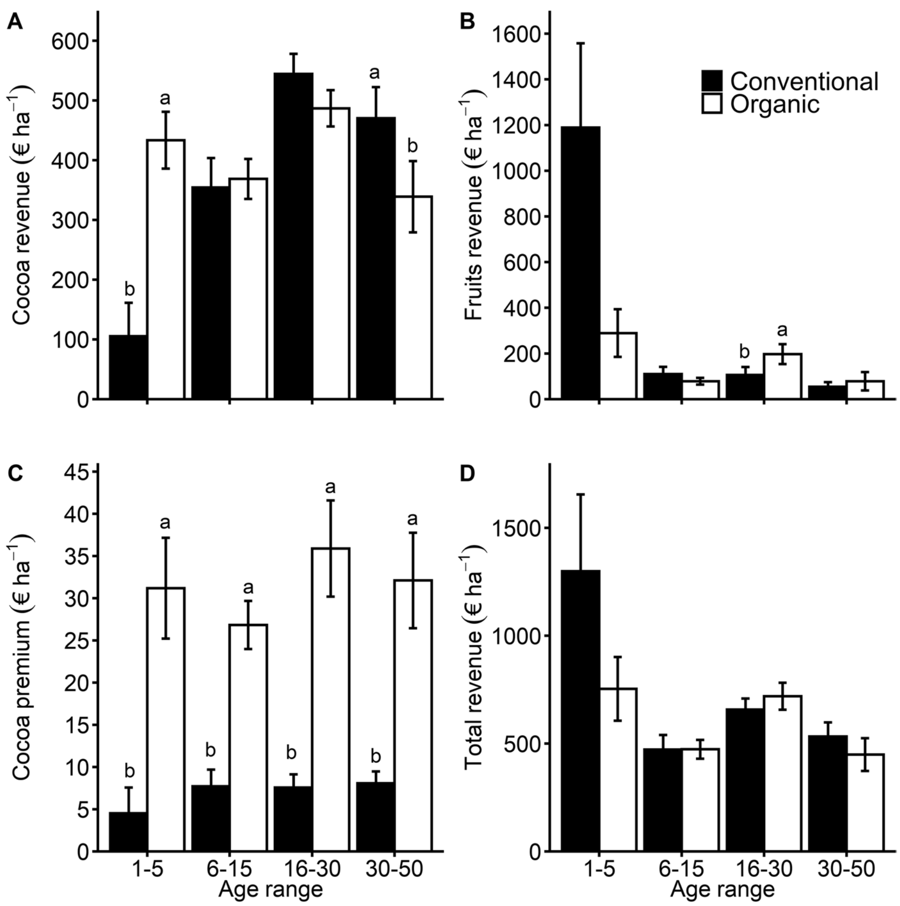

Fig. 2 Revenue for conventional and organic cocoa agroforests in Suhum Municipality, Eastern Region of Ghana in 2019

between age of plantation and C sequestered by total shade trees. Cash flow analyses for each age category of the two production systems were compared using the Mann–Whitney rank sum test. All statistics were undertaken using R 4.0.3 software (R Core Team 2020).

Results

Socioeconomic characteristics

Cocoa production in the two systems was male dominated (Table 2) with a farmer average age of 53 years.

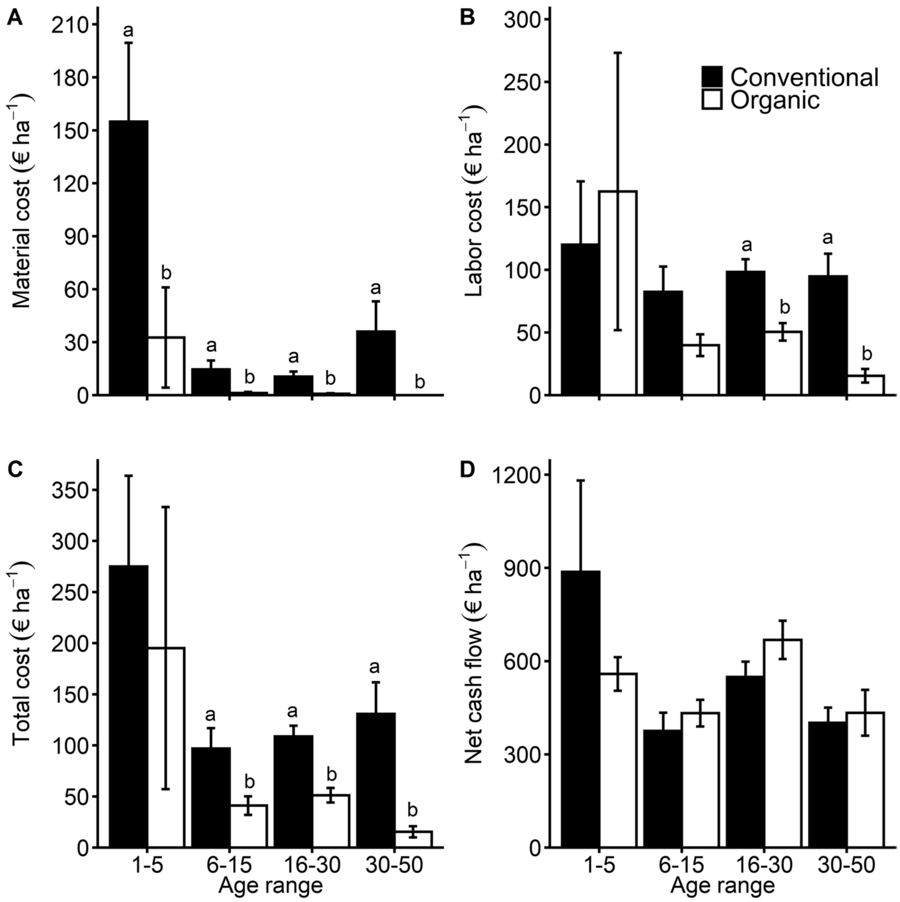

Fig. 3 Cost and net cash flow for conventional and organic cocoa agroforests in Suhum Municipality, Eastern Region of Ghana in 2019

Household and farm sizes in conventional system were 26% and 47%, respectively, greater than in the organic system. The average cocoa yield in this study was 352 kg ha^{-1}.

At the juvenile stage of cocoa agroforests (1–5 years), revenue obtained for cocoa beans was fourfold higher in the organic system than the conventional counterpart (Fig. 2a). However, at the old stage (31–50 years) this revenue source was 39% greater in the conventional system than in the organic counterpart. Across all age ranges, organic system on average benefited from a 357% higher cocoa premium than the conventional system (Fig. 2c). No significant difference was found between cocoa production systems total revenue, although the conventional system's total revenue was 72% greater than that of the organic system (Fig. 2d). On average across all age ranges, material costs in the conventional system were 671% higher than in the organic system (Fig. 3a). In the mature (16–30 years) and old (31–50 years) stages, the organic system on average recorded 194% lower labor cost than the conventional system (Fig. 3b). There was no difference in net cash flow between systems in all age ranges (Fig. 3d).

The NPV of both systems were greater than zero (decision criteria), which indicates that they were profitable (Table 3), although conventional NPV was 20% larger than that of organic systems. Benefit Cost Ratio in the organic system was 32% greater than that of the conventional system. In both systems, BCR was greater than one (decision criteria). Similarly, MIRR of the two systems was three times greater than the discount rate of 8%.

Sensitivity analysis showed that both production systems were profitable under all three scenarios, but had different profitability values (Table 3). In the three scenarios, the greatest reduction in profitability was caused by an increase in interest rate from 8 to 24%. In their response to the interest rate increase, conventional systems had a 166% lower

Table 3 Current financial profitability and sensitivity analysis of conventional and organic cocoa agroforests in Suhum Municipality, Eastern Region of Ghana, 2019; changes in interest rate (Scenario a), yield reduction (Scenario b) and increased production cost (Scenario c)

Profitability indicators and systems	Current financial Profitability	Scenario a: increase of interest rate from 8 to 24%	Scenario b: yield reduction by 20%	Scenario c: increase of production cost by 10%
NPV (€)				
Conventional	7,016	2,639	5,231	6,825
Organic	5,864	1,682	4,466	5,751
BCR				
Conventional	4.7	4.3	3.7	4.3
Organic	6.2	4.0	5.0	5.6
MIRR (%)				
Conventional	17.8	18	17	18
Organic	17.0	17	17	17

NPV: Net Present Value of Net Cash flow, BCR: Benefit Cost Ratio and MIRR: Modified Internal Rate of Return

Table 4 Average tree density and tree basal area in conventional and organic cocoa agroforests in Suhum Municipality, Eastern Region of Ghana in 2019

Structural characteristics	Unit	Conventional	Organic	Overall SEM	*p* value
Cocoa trees density	stems ha^{-1}	1218	1218	74.4	0.98
Fruit trees density	stems ha^{-1}	97	222	41.7	0.03
Timber trees density	stems ha^{-1}	116	130	19.1	0.69
Total shade tree density	stems ha^{-1}	213	353	47.6	0.03
Fruit trees basal area	m^2 ha^{-1}	2	4	0.8	0.05
Timber trees basal area	m^2 ha^{-1}	5	8	1.0	0.13
Total shade trees basal area	m^2 ha^{-1}	7	13	1.1	0.01

Overall SEM denotes the standard error of the mean

NPV, whereas in organic systems such rise in interest reduced NPV by 249% in comparison to current profitability. In scenario b, a reduction of yields by 20% reduced the NPV in both systems by 32% in comparison to current profitability. In scenario c, an increase of costs by 10% lowered NPV by 3% and 2% for conventional and organic systems, respectively.

Carbon sequestration

Cocoa tree and timber tree density as well as timber tree basal area did not significantly differ between systems (Table 4). ANOVA indicated that fruit tree density and fruit tree basal area in organic system were more than 129% and 115% respectively, higher than in conventional systems. Similarly, total shade tree density and basal area in organic systems were up to 66% and 76% respectively, greater than in the conventional counterpart.

Table 5 Average C stocks and CO_2 equivalent of C stocks in t ha^{-1} of conventional and organic cocoa agroforests in Suhum Municipality in the Eastern Region of Ghana in 2019

Carbon pools	Conventional	Organic	Overall SEM	*p* value
Cocoa trees	14	14	1.2	0.83
Fruit trees	4	7	3.1	0.04
Timber trees	35	52	7.7	0.28
Standing litter	2	2	0.2	0.14
SOC	78	99	15.9	0.03
Total C	134	174	19.4	0.04
CO_2 eq. of total C	490	637	71.0	0.04

Means along the same rows with different alphabets are significantly different at ($p < 0.05$). Overall SEM is total standard error of mean

On average, soil, timber trees, cocoa trees, fruit trees, and standing litter stored 54.7%, 29.7%, 10.8%, 3.2%, and 1.6% of the total C sequestered, respectively. In both systems, there was no significant difference in C stocks of cocoa trees, timber trees, and standing litter (Table 5). ANOVA indicated that soil C sequestered in conventional system was 21% lower than organic system (Table 5). Total CO_2 equivalent of total C in organic system was 30% greater than in conventional system. There was a significant positive correlation between age of plantation and total amount of C sequestered by total shade trees (correlation coefficient = 0.51, $p < 0.01$).

Economic profitability

Annual CO_2 accumulation rate was 30.1 t ha^{-1} yr^{-1} and 32.1 t ha^{-1} yr^{-1} for conventional and organic systems, respectively. If only the yearly CO_2 sequestered is valued in Ghana, then at the average EU trading price, conventional system will yield 232 € ha^{-1} yr^{-1} and 246 € ha^{-1} yr^{-1} for organic system. When the estimated social cost of CO_2 is considered, then conventional and organic systems would annually yield 1,392 € ha^{-1} yr^{-1} and 1,482 € ha^{-1} yr^{-1} respectively.

Payment of CO_2 at the EU trading price (7.5 € t^{-1}) increased NPV by 49% and 60% for conventional and organic systems, respectively (Table 6). On average, this CO_2 payment increased the BCR of both systems by 34%. There was an increase in NPV by 209% (conventional) and 267% (organic), when CO_2 was paid at 42 € t^{-1}, which would cover the social costs caused by the emission of CO_2 estimated by the United States Government (Table 6). Payment of CO_2 using the average EU trading price was sufficient to reduce the negative effects of 20% yield reduction and 10%

Table 6 Economic profitability at different CO_2 prices and sensitivity analysis of cocoa agroforests in Suhum Municipality, Eastern Region of Ghana, 2019; changes in interest rate (Scenario a), yield reduction (Scenario b) and increased production cost (Scenario c)

Profitability indicators and systems	Potential economic profitability	Scenario a: increase of interest rate from 8 to 24%	Scenario b: yield reduction by 20%	Scenario c: increase of production cost by 10%
Carbon price at 7.5 € t_{CO2eq}^{-1} (average EU trading price)				
NPV (€)				
Conventional	10,439	3,399	7,278	9,394
Organic	9,374	2,491	6,645	8,485
BCR				
Conventional	6.0	5.2	5.0	5.5
Organic	8.6	5.4	6.9	7.8
MIRR (%)				
Conventional	19	19	18	18
Organic	18	18	18	18
Carbon price at 42 € t_{CO2eq}^{-1} (estimated social cost of CO_2 release)				
NPV (€)				
Conventional	21,689	6,992	16,969	16,579
Organic	21,504	6,327	16,977	16,864
BCR				
Conventional	12.4	9.7	7.8	6.5
Organic	20.0	12.2	9.8	8.9
MIRR (%)				
Conventional	20	20	20	20
Organic	20	20	20	20

NPV: Net Present Value of Net Cash flow, BCR: Benefit Cost Ratio and MIRR: Modified Internal Rate of Return increase in production cost in both systems. When C payment at the estimated social cost is used as revenue source the organic system performs similarly or under certain scenarios outperforms the conventional system. Estimated social cost CO_2 payment increased BCR of the systems three-folds and MIRR by 14%, when compared to current financial profitability.

Discussion

Socioeconomic characteristics

Male domination in cocoa production within this study is in line with studies from other cocoa growing areas in Ghana (Denkyirah et al. 2017; Ameyaw et al. 2018; Kongor et al. 2018). This reflects that men are more endowed with resources such as land than females, as governed through the traditional inheritance system. Another reason may be the recognition of cash crops such as cocoa as a male crop in Africa due to their high labor and capital requirements (Hill and Vigneri 2011). This perception makes it difficult for landowners to engage the services of female sharecroppers. The average farm size of 2 ha is at the lower end of the range of 2 – 5 ha reported for Ghana (Djokoto et al. 2016; Nunoo and Owusu 2017; Kongor et al. 2018). Because cocoa production is labor intensive, farmers keep smaller farm sizes to increase productivity (Aneani and Ofori-Frimpong 2013). Adoption of new agricultural technology was negatively related to farmer's age and farming experience (Aneani et al. 2012; Denkyirah et al. 2017; Akrofi-Atitianti et al. 2018). This explains the predominance of traditional cocoa agroforests in the investigated villages, as the age of farmers was above 50 years with 20 years of experience in cocoa farming on average. Average cocoa yield of 352 kg ha^{-1} in our study is close to the national average of 400 kg ha^{-1} reported by Aneani and Ofori-Frimpong (2013).

Financial profitability

Higher revenue from cocoa beans sale in the organic system at the juvenile stage was due to higher cocoa yield. Lower yield in conventional juvenile cocoa plantations can be associated to higher insecticides application at this stage to sustain the production of maize (*Zea mays* L.) and cassava (*Manihot esculenta* Crantz). These multi-cropping practices led to 311% higher crop revenue in the conventional system. However, spraying of insecticides has been found to reduce cocoa yield by reducing cocoa-pollinating midges (*Forcipomyia* spp.) populations, which eventually results in lowering fruit set (Kwapong and Frimpong-Anin 2013). When the production of these annual crops ceased after the maturity of cocoa plants, the revenue from cocoa sales remained similar for both systems except for the old age ones (31–50 years), when conventional cocoa revenue was 39% greater than organic. Higher cocoa yield at the old age in the conventional system resulted from fertilizer application. Ahenkorah et al. (1974) reported that after 24 years of continuous cropping, fertilizer increased the yield of cocoa agroforests to be 1.3-fold more than those without fertilizer. For the organic system, which benefited from higher cocoa premium than the conventional system, this revenue source was only 4%, 6%, 5%, and 7% of the total revenue at juvenile, young, mature, and old stage, respectively. These results justify cocoa farmer assertions about the insufficiency of cocoa premiums (Skalidou 2018; Kissi 2021).

Between the two systems, total cost in the conventional system was higher than in the organic confirming reports made by Sgroi, et al. (2015a, b) in olive (*Olea europaea* L.) cultivation in Sicily. Because cocoa cultivation is labor intensive, on average it was responsible for 78% of total cost. Lower labor costs incurred in the organic system (i.e. mature and old stages) supports observations made in agroforests with cocoa (Armengot et al. 2016) and coffee (Lyngbaek et al. 2001). However, it contradicts data from hazelnut – *Corylus avellana* L. (Demiryurek and Ceyhan 2008; Tanrivermis 2008), rice – *Oryza sativa* L. (Suwanmaneepong et al. 2020), and maize – *Zea mays* L. (Adamtey et al. 2016) cultivation. Contrary to our study, which took place in an agroforestry setting, the above authors' findings came from monocultures, which may explain the differences. Although in our study both managements are agroforests, the tree density (cocoa and shade trees) was higher in organic farms, which limits the penetration of light to stimulate weed growth (Pumariño et al. 2015). This probably demonstrates the ability of organic agroforests to suppress weed growth, which reduces labor requirement for weed control. As conventional cocoa farmers combat weed and pest infestations, they invest in manual weeding in addition to hiring labor to apply herbicides and other chemical inputs, which increases their labor cost. Furthermore, some authors (Denkyirah et al. 2016; Obiri et al. 2021) observed excess utilization of agrochemicals among conventional Ghanaian cocoa farmers, which leads to an increase in their overall cost. During fertilization, it is recommended that mineral fertilizers are applied as a circular band 20–40 cm around the base of the cocoa tree (Opoku-Ameyaw et al. 2010) which is tedious and increases the labor requirements of conventional farmers. As organic cocoa agroforests are basically independent of fossil fuel, they are also more energy efficient (Neira 2016). Following organic principles therefore leads to a reduction in production costs (Tzouvelekas et al. 2001).

Even without accounting for revenue from timber, all systems were profitable confirming a similar assertion made by Duguma et al. (2001). Similarly in the Western and Ashanti Region of Ghana, discounted cash flow techniques have been used to show the profitability of TCAFS (Obiri et al. 2007; Nunoo & Owusu 2017). Among the profitability indicators, it was only MIRR, which showed no difference between the production systems. Three-fold higher MIRR than the 8% interest rate falls within 100% to 300% return to investment for cocoa agroforesters in Ghana (Obiri et al. 2007; Asare et al. 2014; Nunoo and Owusu 2017).

Net present value was 20% higher in the conventional cultivation system than in its organic counterpart. During the earlier years of farm establishment (1–5 years), net cash flow of organic farms was 7 times lower than that of conventional farms due to 43% lower revenue in organic farms. The lower revenue was due to lower food crop yield. Land clearing prior to cocoa planting is associated with burning plant biomass (Arévalo-Gardini et al. 2015) leading to nutrient losses through volatilization, leaching and wind erosion (Young 1990). In organic systems, where farmers do not replace these nutrients, lower yields for food crops are the consequence. This reflects the role of crop diversification in cocoa agroforestry systems highlighted by Abdulai et al. (2018) and Cerda et al. (2014) under changing climatic conditions. In Ghana, the major season for cocoa harvesting lasts from October to March and the minor season from May to August (Opoku-Ameyaw et al. 2010). After these purchasing periods, food crop consumption and sales sustain farmers' livelihoods. It is for this reason that 49% and 27% of total revenue resulted from food sales on conventional and organic farms, respectively. These results also indicate the high financial burden on organic farmers during the farm establishment phase. This adversely affects the adoption of cocoa organic management because of farmers' high preference for present day payoff rather than long term future profits (Rasul and Thapa 2006; Do et al. 2020). Our findings contradict greater NPV for organic than conventional systems in orchards of lemon – *Citrus limon* (L.) Osbeck and olive – *Olea europaea* (Sgroi et al. 2015a, b) in Sicily. These contrasting results from plantations may be due to the fact that our study took place in a mixed cropping setting that usually allows for revenues from other crops throughout the year.

In the sensitivity analysis, the NPV reacted more to a 300% increase in interest rate (scenario a) in both systems than to a 20% yield loss (scenario b) or a 10% increase in cost (scenario b). The observed reduction was even more severe in organic (81%) than conventional (62%) farming systems. This was because of the negative correlation between NPV and discount rate (Ataniyazova et al. 2014; Do et al. 2020). Also, increased interest rates affected more present cash streams than future ones (Kalyebara and Islam 2014). Among the profitability indices, NPV is the most suitable because it indicates the amount of money generated from a made investment and is comparatively easy to understand (Thapa and Weber 1994).

The BCR as a profitability indicator demonstrates whether the revenue obtained is worth the input costs of the systems. All systems had a BCR > 1 demonstrating their profitability. However, our results show that the organic system was 32% more efficient in cost invested to obtain revenue than its conventional counterpart. For smallholder cocoa farmers with limited resources, this serves as a justification to practice organic cocoa production.

Although important for agricultural systems' profitability calculations, opportunity costs were not considered in our study as compared to a study from Bangladesh, where opportunity cost reduced agroforestry systems' profitability by 72% (Rasul and Thapa 2006). This was because agriculture is the predominant source of employment in our study area, employing about 50% of the population in Suhum Municipality (MOFA 2017). Also, within the agriculture sector, cocoa production receives a lot of governmental support in terms of extension services and subsidies making it an attractive agricultural venture for farmers. Additionally, state regulation and standardization of annual cocoa beans prices (Kolavalli and Vigneri 2011) ensures guaranteed annual revenues to farmers. Lastly, growing cocoa in agroforestry systems offers farmers the opportunity to benefit from the yields of other crops, offering thus ample employment opportunities. Thus, the opportunity costs were assumed to be de facto zero.

Carbon sequestration

The average total C sequestration of 153 t ha^{-1} in this study is in accordance with average C sequestrations of 140 t ha^{-1} to 155 t ha^{-1} found in Ghana, Bolivia, and Ecuador (Asase et al. 2008; Jacobi et al. 2014; Jadan et al. 2015). Higher C sequestration of up to 266 t ha^{-1} were found in cocoa agroforests of Ghana with larger shade trees, storing more than 50% of the total C stocks (Dawoe et al. 2014; Asase and Tetteh 2016). Comparing the time lapse between their study and this study could imply that with deceasing timber resources in Ghana, these traditional cocoa agroforests are now becoming the new frontier for timber harvesting (Ruf 2011). However, this assertion needs further investigation to quantify the disappearance rates of shade trees in traditional cocoa agroforestry landscapes. Another reason for the lower C estimates of our study in comparison to those of the authors above may be the presence of older farms than those in our study. We observed a significant positive correlation between farm age and C stocks in shade trees, which supports findings of higher C stocks in shade trees as cocoa farm ages reported by Madountsap et al. (2018) and Saj et al. (2017).

Forests are major sinks for CO_2 in terrestrial ecosystems (Jadan et al. 2015; Asase and Tetteh 2016). Hence transforming forests into cocoa agroforests leads to losses of biomass and CO_2 into the atmosphere (Obeng and Aguilar 2015). The Atewa Forest, which is a primary forest close to the study area, is reported to hold C stocks of 304 t ha^{-1} (Asase and Tetteh 2016). The implication is that 50% of the C stocks in primary forests are lost when they are converted to traditional agroforests (Duguma et al. 2001). However, this loss is still lower than in primary forests that have been converted to simple cocoa-*Gliricidia sepium* (Jacq.) Steud. shade agroforests (Sari et al. 2020) and cocoa monoculture (Asase et al. 2008) loosing up to 80% of C stocks. Though traditional cocoa agroforests cannot replace the C sequestration function of natural forests, converting cocoa monocultures and simple agroforests into multi-strata complex agroforests will play a crucial role in reducing C losses and increasing C sequestration.

Total C sequestered was 30% higher in organic system than in their conventional counterpart, which is close to 40% higher total C stocks in organically managed coffee agroforests than in their conventional counterparts in Costa Rica (Häger 2012). In our study, this disparity between the two cultivation systems was mainly due to 27% higher SOC in the organic compared to the conventional system (Table 5). The average soil C (88 t ha^{-1}) of this study is comparable to studies in Ghana (Mohammed et al. 2015), Bolivia (Jadan et al. 2015), and Brazil (Gama-Rodrigues et al. 2010), which ranges from 62 t ha^{-1} to 127 t ha^{-1} for a soil depth of 0–30 cm and proves the importance of cocoa soil C sequestration (contributing 57% of total C sinks). A limitation of this C sequestration was only measured to a depth of 30 cm, although cocoa tree and shade roots extend beyond 30 cm (Saputra et al. 2020) leading to C sequestration even at 100 cm soil depth and deeper (Gama-Rodrigues et al. 2010). Thus the C stocks in our systems are likely underestimated and are higher than reported. It should be noted that two farms in conventional and organic systems, had soil C stocks above 300 t ha^{-1} demonstrating the high heterogeneity of the soils under these cocoa agroforestry systems. Standing litter is primarily regulated by the rate of litterfall and its subsequent decomposition (Briggs 2004). The similarity in the quantity of standing litter of both systems suggests that litterfall and decomposition are likely not affected by different management systems. This observation confirms findings of Fontes et al. (2014), who observed no difference in standing litter, litterfall, and decomposition between fertilized and unfertilized traditional cocoa agroforests established on both Latosols and Cambisols.

Economic profitability

The inclusion of theoretical C payments positively impacted both production systems' profitability. Similarly, theoretical C payments as a source of revenue have been reported to increase profitability in agroforests in Ghana (cocoa, Asare et al. 2014), Brazil (coffee, Goncalves et al. 2021) and Ethiopia (homegardens, Walde et al. 2020). This revenue source increased NPV between 55 to 311% using the average EU trading price and estimated social costs of CO_2 release, respectively, which is comparable to a profitability increase range of 60% to 300% reported by Walde et al. (2020) and Asare et al. (2014). However, findings of this study contradicts Goncalves et al. (2021), who reported less than 1% and 1.4% increases in NPV where current and social CO_2 payments, respectively, were used as revenue source. The disparity likely reflects less revenue from CO_2 payments reported by the above authors because their average C sequestered was with 61 t ha^{-1}, 2.5-fold lower than the average we report. With the inclusion of average EU CO_2 payment, the organic system NPV still lagged marginally behind the conventional system. This was mainly caused by high initial investment costs (1–5 years) in organic farming systems. However, with CO_2 payments in height of the estimated social costs for CO_2 release, organic cocoa agroforests became similarly profitable in terms of NPV as conventional cocoa agroforests. Considering C payment as an incentive for adoption of organic farming, its value must not be less than the high price estimated by the United States Government. Our results show the importance of C payments on farm profitability, when interest rates increase, yields decline, or production cost increase. For example, the addition of low C payments increased conventional (45%) and organic (110%) systems' resilience to the three folds increase in interest rate (scenario a). This resilience was further increased by 250% and 624% for conventional and organic systems, respectively, with high C payments. It is important to mention that our study only addressed C sequestration as one of many environmental benefits of TCAFS. If other ecosystem benefits such as biodiversity conservation are valued, then organic production may become even more profitable. Organic production systems have been observed to harbor more biodiversity than their conventional counterparts (Fuller et al. 2005; Asigbaase et al. 2019; Stein-Bachinger et al. 2020). Cocoa premium alone may not be sufficient to induce conventional agroforesters to transform to organic cultivation. However, additional premiums from other fruits and crops in addition to C payments may add to the arguments for certified organic cocoa agroforestry. Although cocoa monoculture has been reported to be more profitable than traditional cocoa agroforests (Obiri et al. 2007), such environmental payments will have the potential to facilitate the transition of monocultures to a more sustainable land use (Asare et al. 2014).

Short term C payments have been shown to be effective in transforming degraded pastures from simple to complex silvopastoral systems in Nicaragua (Pagiola et al. 2007). However, the authors noted a high likelihood of farmers reverting to their unsustainable land use when funding ends. For C payments to be reality there needs to be a long-term funding source. Helping farmers to trade C sequestered in voluntary C markets, which has been successful for agroforesters in Mexico in the Scolel Te´ project (Tipper 2002), may be a sustainable funding source. The Clean Development Mechanism (CDM) also offers a funding source especially for African cocoa producing countries considering the fact that African countries have underexploited this mechanism (Röttgers and Grote 2014; Kreibich et al. 2016). Another issue that needs to be addressed is the standardization of methodologies for C accounting (Perez et al. 2007; Smith et al. 2007). This is due to the aggregation of C sequestered in small plots to a scale large enough to trade it in C markets which requires a rapid, cost effective and feasible way for estimating C stocks (Perez et al. 2007). Capacity building is therefore needed in cocoa producing countries on the use of GIS, remote sensing and machine learning tools to validate C sequestration in this agroecosystem (Perez et al. 2007). Furthermore, there is a high possibility of abuse and conflicts if farmers are not adequately educated in addition to their access to information regarding C trading contracts. For example farmers must understand that they will not receive market prices for sequestered C due to operational cost accrued in the process of selling C (Tipper 2002; Smith et al. 2007). Absence of land and tree ownership rights by cocoa sharecroppers and land title certificates by land owners will greatly affect the implementation of C payments if not properly addressed (Smith et al. 2007;

Jaza Folefack and Darr 2021). Because of such hurdles C payments for African cocoa agroforesters in the short term may not be feasible (Jaza Folefack and Darr 2021).

Conclusions

Across different age ranges of cocoa plantations there was no difference in net cash flow between the organic and conventional systems. Financially both systems were profitable, but conventional NPV was 20% greater than organic under the current situation. Contrary to NPV, BCR for the organic system was 32% greater than in the conventional system. A three times increase in interest rate was the production constraint that had the most negative effect on both production systems. In addition, increased interest rates negatively affected the organic systems more than the conventional ones, which resulted from a longer time for organic farmers to receive returns from their initial investments. The organic system sequesters more C than the conventional system. Carbon sequestration payments using the average EU trading price and estimated social price on average increased NPV of systems by 55% and 311%, respectively. Our study showed that when considering C payments as an incentive to motivate cocoa agroforests in the Suhum Municipality to switch from conventional management to organic, their amount must be at least 42 € t_{CO2eq}^{-1}.

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