



Promoting cocoa agroforestry under conditions of separated ownership of land and trees: Strengthening customary tenure institutions in Cameroon

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ABSTRACT

Formal and customary land tenure can encourage the adoption of sustainable land management practices. Yet, certain forms of customary land tenure can deter farmers from practicing agroforestry. One such example is the case of cocoa agroforestry in the Centre region of Cameroon, where cocoa orchards and the fruit trees that grow inside were traditionally inherited separately to different family members. While customary land owners hesitate to allow tree cultivation in their cocoa orchards as they are afraid of losing out while sharing their land, the tree owners would often like to expand the number of fruit trees, but lack the land to do so. This study assessed how various policy instruments can enhance the adoption of agroforestry in this context. Using the Coase theorem, we analyzed seven agroforestry systems of cocoa in association with Safout (*Dacryodes edulis*), Bush mango (*Irvingia gabonensis*) and/or Ndjansang (*Ricinodendron heudelotii*). Land sharing with fruit producers reduced the cocoa mono-croppers' farm income by 40–80%, while fruit producers benefited especially from the cultivation of Bush mango. According to our baseline Coase theorem results, cocoa agroforestry was socially efficient when 13–60 fruit trees/ha were planted, providing a positive net social benefit (248,753 to 3,394,829 FCFA/ha). The policy intervention scenarios (cocoa certification, payment from voluntary carbon projects and reform of the current customary tenure system) led to more fruit trees being planted (14–71 trees/ha) and increased the net social benefit (266,418 to 5,753,595 FCFA/ha). Both farmer categories gained in each of the scenarios, with the fruit producers benefiting more than the cocoa croppers. Among the investigated policy instruments, a land tenure reform inducing a fair revenue sharing proved to be the most effective in encouraging tree planting in cocoa farms.

1. Introduction

Land and tree tenure rights have been identified as important factors encouraging the adoption of agroforestry and further sustainable land management practices (Place, 2009; Neef and Heidhues, 1994; Nkomoki et al., 2018). Formal land titles that provide tenure security to small-holder producers can improve the farmers' access to credit, encourage their use of farm inputs, stimulate land markets and long-term investments in land productivity (Place, 2009). While these benefits are generally uncontested, real progress towards formalizing customary land rights is slow in many parts of the global South (Chimhowu, 2019; Murray Li, 2020). Consequently, focus has shifted towards customary and non-formal land tenure arrangements and their role in providing tenure security (Van Leeuwen, 2014; Borelli et al., 2019). Studies find that farmers sometimes also adopt agroforestry under such

arrangements, e.g. on land they don't formally own (Keeley et al., 2019; van der Meer Simo et al., 2020). At the same time there is abundant evidence that certain forms of customary land tenure can represent severe obstacles to agroforestry adoption (Weinstock and Vergara, 1987; Borelli et al., 2019).

This paper aims to investigate how agroforestry can be promoted in situations where customary land tenure prevails. More specifically, we analyze the effect of market-based and regulatory policy instruments in this context, viz. cocoa sustainability certification, payments for voluntary carbon projects, and a reform of the current customary tenure system. While many studies have corroborated the effect of customary vs. statutory land tenure on agroforestry adoption, research on this subject is relatively rare. Given the global prevalence of land tenure insecurity, in addition to its academic appeal this question is of high practical relevance. Applying the Coase theorem (Coase, 1960) to the

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example of cocoa (*Theobroma cacao*) agroforestry, we study this question in the Centre region of Cameroon, where a customary land tenure system exists that separates the ownership of land and trees, and about 75% of farmers are traditional cocoa cultivators (Sonwa et al., 2014; Jaza et al., 2015).

In response to a deteriorating cocoa world market, cocoa farmers in this region have been encouraged since the early 1990s to diversify their production through introducing fruit trees inside their cocoa plantations (Minader Ministère de l'Agriculture et du Développement Rural, 2018). ICRAF's tree domestication program established in 1996 prioritized domestic fruit tree species such as Safout (*Dacryodes edulis*), Bush mango (*Irvingia gabonensis*) and Ndjansang (*Ricinodendron heudelotii*) for cocoa agroforestry (Jagoret et al., 2006; Degrande et al., 2007). However, levels of cocoa agroforestry adoption generally remain low to date. Only one-third of cocoa croppers in the region have planted fruit trees or other tree species in their cocoa orchards (Nkamleu and Manyong, 2005; Foundjem-Tita et al., 2013) despite the fact that cocoa agroforestry can be more profitable than cocoa mono-cropping (Todem, 2005; Jagoret et al., 2008; Eboutou, 2010; Kwessey, 2010; Jaza et al., 2015). This may dramatically jeopardize Cameroon's cocoa exports in the future, as major importing countries demand sustainability certification for cocoa imports from 2025 onwards (Mbougha, 2015; Ngwack, 2017) and common certification schemes encourage farmers to grow cocoa in agroforestry systems to comply with their standards.

In addition to widespread adoption barriers such as a lack of capital to invest in agroforestry establishment; poorly developed marketing structures and processing facilities; strong fluctuations of market prices; and a lack of knowledge, advisory services and planting materials for fruit tree cultivation, the customary land tenure system that separates the ownership of land and trees represents a major impediment to agroforestry adoption in the region (Nkamleu and Manyong, 2005; Foundjem-Tita et al., 2013; O'Sullivan et al., 2018). This customary practice prevails on nearly 44% of local farms (Cotula and Mayers, 2009; Eboutou, 2010; Jaza et al., 2015; Kahler, 2018) and reflects the increasing land scarcity, as a consequence of which land and fruit trees were traditionally inherited separately to different family members when a farmer died. As a consequence of this customary practice two groups of customary land and customary tree owners emerge, which each lack complementary resources for cocoa agroforestry: While the land owners are largely deterred by above adoption barriers, the tree owners possess the required knowledge and experience in tree management and would often like to expand the number of fruit trees, but lack the land to do so.

Our paper contributes to the literature at two levels: At a conceptual level, we advance the understanding of how agroforestry adoption can be encouraged under customary tenure arrangements that separate the ownership of land and trees, i.e. when the interests of land owners ("cocoa cropper") and tree owners ("fruit producer") need to be aligned. At the empirical level, our analysis of concrete policy instruments and the related costs and benefits to both parties can contribute to further developing local agroforestry systems and policies to promote fruit tree planting in cocoa orchards under such conditions.

In the following, we (i) briefly characterize the most common locally prevailing cocoa agroforestry systems in terms of fruit tree density and benefits to both parties; (ii) compare the net social benefit generated by these systems; and (iii) model how distinct market-based and regulatory policy instruments would affect these systems. Results will help design effective policies aiming to promote cocoa agroforestry in Cameroon and similar conditions where informal land and tree tenure prevails.

2. The current land tenure system as a constraint to agroforestry adoption

In many African societies land rights are torn between traditional property rights and modern laws (Tchapmegni, 2007). In pre-colonial times, land in most parts of the continent was perceived as communal

property. The customary land tenure system prevailing today still reaches back to that period (Schreckenberget al., 2002; Cotula et al., 2004; Tchapmegni, 2007; Cotula and Mayers, 2009; ADB African Development Bank, 2009; Oyono, 2009).

Formal individual rights to land in Cameroon were introduced during the colonial period. Land registration and recognition of formal private land ownership in principle is based on customary land rights confirmed by community members and village chiefs (Firmin-Sellers and Sellers, 1999; Ngwasiri et al., 2002; ADB African Development Bank, 2009; Oyono, 2009). However, with currently only 2% of land being officially registered in Cameroon (Foundjem-Tita et al., 2013; Kahler, 2018), most Cameroonians do currently not hold formal land titles and hence face significant land and tree tenure insecurity. This seriously limits smallholder producers' economic rights to exploit the trees planted on their farms and represents a major limitation to agroforestry adoption (Lawson et al., 2002; Cotula and Mayers, 2009; Foundjem-Tita et al., 2013; Haglung et al., 2011; Leakey, 2011; Jagoret et al., 2019).

Under the customary tenure system prevailing in the study region, a child could inherit a tree on land belonging to another person of the same family (Cotula and Mayers, 2009; Jaza et al., 2015; Kahler, 2018) based on the patrilineal transmission of inheritance rights (Dkamela, 2011). These rights are superimposed on lands and resources and are exercised by family, lineage and village. They are guaranteed by the moral authority of the elders and other traditional authorities, i.e. head of the family, head of the lineage or the village head with the council of notables, who settle conflicts and thus act as a customary tribunal (Dkamela, 2011; Kahler, 2018). Such traditional land tenure arrangements are still widespread, scrupulously respected by the communities, and often even more effective than formal legal regulations and mechanisms (Foundjem-Tita, 2013).

Based on Schlager and Ostrom's (1992) framework, the customary property rights of land and trees entail that fruit producers (i) can access the land at any time; and (ii) are allowed to replace old fruit trees, while they cannot extend the fruit tree plantation to other parts of the land. Furthermore, cocoa croppers (iii) could plant any types of crops under the fruit trees; while (iv) they are not allowed to harvest fruits which entirely belong to tree owners and vice-versa. Cocoa croppers are (v) also in charge of the overall management of the land in terms of internal use patterns, land improvement and transformation; and (vi) they are not allowed to lease or sell the land, which is only transferable to their successors once they will die.

Cocoa croppers are typically not compensated for the loss arising from tree production on their farms (Cotula and Mayers, 2009; Kahler, 2018). Hence, they are typically unwilling to allow fruit tree growers to plant or expand the number of trees in their cocoa orchards, which limits the expansion of cocoa agroforestry. In the absence of significant progress in land titling in the study region, the introduction of negotiated mechanisms of benefit sharing between land owners and tree growers to the customary tenure system could provide the necessary incentives for a wider adoption of cocoa agroforestry. We will compare this with the effect of selected policy instruments on the adoption of cocoa agroforestry in the following sections of our paper.

3. Data and methods

3.1. Field survey

The study used both primary and secondary data. The primary data were collected during a field survey conducted from June to August 2019 in the Centre region of Cameroon. This region extends over 68,945 km² between 3° and 6°N and 10–13°E (Minepat Ministère du Plan et de l'Aménagement du Territoire, 2013). A mean annual temperature of 25 °C, rainfall of 1,500–2,000 mm and ferralitic, acid and clay soils favor the cultivation of cocoa and fruit trees in this area (Minepat Ministère du Plan et de l'Aménagement du Territoire, 2013). Benefiting from its

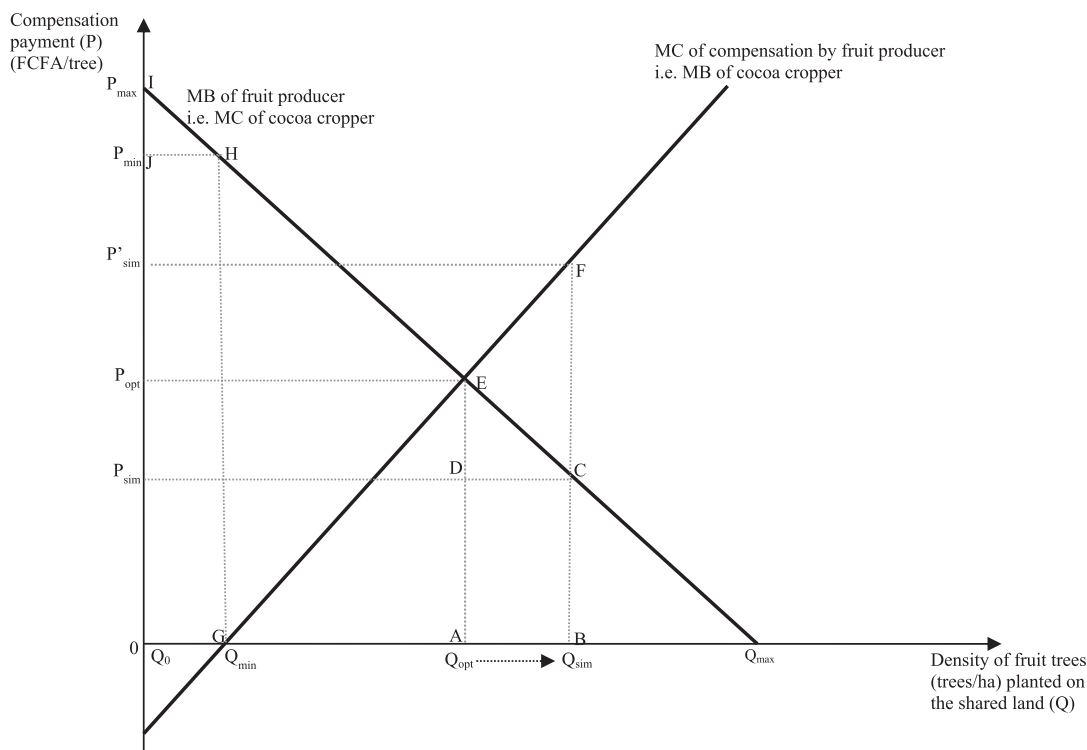


Fig. 1. Coase theorem illustrating the fruit producer’s externality in the cocoa cropper’s land.

strategic geographical location and proximity to the country’s capital city Yaoundé, this region is among the centers of cocoa and fruit production. It was chosen for this study due to (i) the ubiquity of cocoa orchards in this region contributing almost half of the national cocoa production (Mbougha, 2015; Eboutou, 2010); (ii) the prevalence of customary land tenure arrangements separating ownership of land and trees (Eboutou, 2010; O’Sullivan et al., 2018); and (iii) the gradual expansion of cocoa agroforestry since the launch of ICRAF’s tree domestication program in 1996 (Degrande et al., 2007).

Two villages were randomly chosen in five randomly selected divisions. Each of the 10 villages was selected to represent the following three fruit tree species of interest, i.e. Safout [S], Bush mango [M] and Ndjansang [N] and their possible combinations with Cocoa [C]. These fruit tree species were selected due to their local importance and market potential, and because they had been identified as local priority species by ICRAF (Degrande et al., 2006; Eboutou, 2010). Hence, the following agroforestry systems were studied in addition to cocoa mono-cropping [C]: [C+S], [C+M], [C+N], [C+S+M], [C+S+N], [C+M+N] and [C+S+M+N].

To ensure comparability of yield data across the various farms and study sites, we only included cocoa plantations and fruit trees at their most productive age (between 5 and 20 years) following Nerlove (1958). Based on these criteria, the survey selected 21 farmers (11 cocoa croppers and 10 fruit producers) in each village, which translated into a combined total of 210 farmers throughout the whole study area. The selected cocoa croppers were customary owners of their lands, had been practising cocoa monoculture in the past and are currently sharing their land with fruit producers. The selected fruit producers inherited trees growing inside the cocoa farmers’ land. Our sampling frame also accounted for regional differences in fruit tree suitability across the study villages (see Tables A7 and A8 in the Appendix 1).

As land and tree tenure conditions as well as agroforestry adoption had not changed much over the last decades, historical or times series data were not necessary for this study. Hence, cross-sectional primary data of the cropping season 2018/2019 were collected from cocoa croppers and fruit producers using a prepared questionnaire and

interview-schedule. The survey served to collect data such as the cultivated land area (ha), number of trees on farm (trees/ha), cocoa yield (kg/ha), decrease in cocoa yield since the introduction of agroforestry (kg/ha), actual revenue generated from cocoa production and/or fruit trees (FCFA/ha), and revenue foregone by cocoa croppers since the introduction of agroforestry (FCFA/ha). As tree data had to be collected through survey rather than bio-physical inventories due to resource and time constraints potentially representing a limitation of our study, we aimed to alleviate this shortcoming by carefully triangulating survey data with observation and information obtained from other respondents.

Primary data were supplemented by secondary data from various sources including academic and technical project publications on agroforestry and the cocoa sector in Cameroon. Secondary data on the prices and production quantities of fruits (Table A1) were used to estimate the total benefit and total cost functions in relation to fruit tree density (Table A3). Data on spacing, height and contribution to shade of tree species (Table A2) was used to analyze the structure of cocoa cropping systems. Data on the discounted benefits of cocoa agroforestry systems (Table A6), as well as the value of fruit trees and agroforestry for biodiversity conservation, soil protection, and further environmental, social and economic benefits (Table A9) were used to compute the net social benefit of the agroforestry systems. Data on carbon stock, sequestration rate and value for selected agroforestry species (Table A1) were used to analyze the scenario results on payment from voluntary carbon projects.

3.2. Theoretical illustration of the Coase theorem to the research problem

This research deals with a land management problem between a land owner who grows cocoa in monoculture on her land, and a fruit producer who intends to use the same land to grow fruit trees. We approach this problem by using the Coase theorem (Coase, 1960). Compared to the analysis of opportunity cost, real options and other alternative approaches it allows to determine the mutually beneficial and socially efficient solution for situations, in which one party causes externalities to another. While some of its assumptions have been criticized as

unrealistic, such as the premises of well-defined property rights, zero transaction cost, and completeness of information; and it is inherently limited to situations in which the negotiators represent single individuals rather than groups of multiple individuals (Hahnel and Sheeran, 2009; Halpin, 2007; Posin, 1999; Wener, 2011), the Coase theorem remains the main approach used in recent literature to solve externality problems in land use and management (Farrell, 1987; Posner, 1993; Medema and Samuels, 1997; McCloskey, 1998; Butler and Garnet, 2003; Ishiguro, 2003; Jaza, 2014).

Although the agronomic effect of introducing fruit trees into cocoa plantations depends on the concrete design of the agroforestry system, the fruit trees in principle tend to compete with the cocoa plants and hence reduce cocoa yield up to 40–80% (Degrande et al., 2006; Gockowski et al., 2013). The activity of the fruit producer, therefore, creates an externality to the cocoa cropper. In accordance with the Coase theorem (Coase, 1960), we assume that the fruit producer makes a payment to the cocoa cropper (represented at the y-axis) in order to compensate for the externality created in her land, which is a function of the number of fruit trees planted (represented on the x-axis).

Fig. 1 illustrates this problem indicating the four main externality points: The solution which equally satisfies both parties is reached at the socially efficient agroforestry point Q_{opt} . Zero agroforestry (i.e. full-sun cocoa production) is achieved at Q_0 , whereas maximum and minimum agroforestry practices occur at points Q_{max} and Q_{min} , respectively.

3.3. Mathematical expressions of the Coase theorem application

3.3.1. Optimal fruit tree density computed from benefit and cost functions

In order to illustrate the Coase theorem, it is necessary to estimate the curves of the fruit producer's marginal benefit (MB) and marginal cost (MC) of compensation (Coase, 1960; Halpin, 2007; Hahnel and Sheeran, 2009). As represented in Fig. 1 the fruit producer's marginal cost¹ (MC) of compensation also represents the cocoa cropper's marginal benefit² (MB) if the fruit producer resigns from planting one additional tree on the shared land. The socially efficient agroforestry point, net social benefit and welfare gain by the two parties are subsequently computed from the two marginal curves MB and MC (Coase, 1960; Farrell, 1987, McCloskey, 1998; Jaza, 2014). Each marginal function is easily derived from the mathematical expression of its total quadratic function.

Generally, the quadratic functions of the total benefit (TB) of fruit producer and total cost (TC) of compensation by the fruit producer are mathematically expressed as a function of the number of fruit trees (Q) planted on the shared land (Eqs. 1 and 2). The choice of the quadratic forms for the TB and TC functions is motivated by the law of diminishing marginal returns inherent in yield functions (Heady and Dillon, 1961; Doll and Orazem, 1978; Debertin, 1986; Wooldridge, 2013).

$$TB = a + bQ - cQ^2 \tag{1}$$

$$TC = a' + b'Q + c'Q^2 \tag{2}$$

From the above equations, the marginal benefit (MB) and marginal cost (MC) can be computed as a function of Q (Eqs. 3 and 4):

$$MB = \frac{\partial TB}{\partial Q} = b - 2cQ \tag{3}$$

$$MC = \frac{\partial TC}{\partial Q} = b' + 2c'Q \tag{4}$$

At the socially efficient agroforestry point, the optimal density of

¹ MC: marginal cost (MC) of compensation by fruit producer=marginal benefit of the cocoa cropper.

² MB: marginal benefit (MB) of fruit producer=Fruit producer's Willingness-To-Pay (WTP)=marginal cost of the cocoa cropper.

fruit trees (Q_{opt}) is obtained by setting MB=MC and solving for Q, which gives Eq. (5):

$$Q_{opt} = \frac{(b - b')}{(2c' + 2c)} \tag{5}$$

Both parties engage in negotiation when a minimum number of fruit trees (Q_{min}) should be planted on the shared land. This is mathematically computed by setting MC = 0, which gives Eq. (6):

$$Q_{min} = \frac{-b'}{2c'} \tag{6}$$

Similarly, the maximum fruit tree density (Q_{max}) that the fruit producer could grow on the shared land is obtained by setting MB = 0, which gives Eq. (7):

$$Q_{max} = \frac{-b}{2c} \tag{7}$$

Where: TB is the total benefit of fruit producer (in FCFA/ha); TC: total cost of compensation by fruit producer (in FCFA/ha); MB: marginal benefit of fruit producer (in FCFA/ha); MC: marginal cost of compensation by fruit producer (in FCFA/ha); Q: number of fruit trees planted on the shared land (trees/ha); Q_{opt} : optimal density of fruit trees at the socially efficient agroforestry point (trees/ha); Q_{min} : minimum number of planted fruit trees to engage in negotiation; Q_{max} : fruit tree density maximizing the benefit of fruit producer; a, b, c, a', b', c': coefficients of the quadratic functions to be estimated from field survey data.

Following the assumptions of the Coase theorem (Coase, 1937), the fruit producer's TB was computed by subtracting fruit production costs (labour, transport, storage, processing, marketing, information expenses etc.) from the revenue (production volume sold times price received) (Eq. 1). In Eq. (2), TC of compensation by the fruit producer includes the main costs supported by the cocoa cropper (charges for land management, land improvement and transformation). The costs of inputs for cocoa cultivation (mineral fertilizer, animal manure, labour, pesticides and seedlings) were entirely borne by the cocoa cropper.

3.3.2. Net social benefit and welfare gain by farmers by planting additional fruit trees from the socially efficient agroforestry point

The socially efficient agroforestry point Q_{opt} , at which the two parties would reach a compromise, is achieved when the fruit producer's MB is equal to its MC (Fig. 1). It is therefore important to determine how this solution contributes to social welfare. Towards this aim, the Net Social Benefit (NSB) representing the private, social and environmental returns and externalities of the various agroforestry systems (Table A9) can be computed as the aggregated benefits *minus* costs at the socially efficient agroforestry point, depicted by the area OIEG0 in Fig. 1, and represented mathematically as follows (Eq. 8):

$$NSB = \frac{(P_{max} + P_{min}) * Q_{min}}{2} + \frac{P_{min} * (Q_{opt} - Q_{min})}{2} \tag{8}$$

Let us assume that the number of trees per hectare increases beyond the socially efficient agroforestry point. This leads to an outwards shift from Q_{opt} to Q_{sim} in Fig. 1, resulting in a welfare gain to each farmer's category. In Fig. 1, the gain of the fruit producer (Gain_{fruiter}) is represented by the rectangle ABCD, which can mathematically be expressed as (Eq. 9):

$$Gain_{fruiter} = (Q_{sim} - Q_{opt}) * P_{sim} \tag{9}$$

Likewise, the gain of the cocoa cropper (Gain_{cropper}) is depicted as the trapezoid DCFE, which is mathematically expressed as (Eq. 10):

$$Gain_{cropper} = \frac{[(P'_{sim} - P_{sim}) + (P_{opt} - P_{sim})] * (Q_{sim} - Q_{opt})}{2} \tag{10}$$

In Eqs. (8)–(10), the compensation payment by the fruit producer (in FCFA/tree) was denoted as follows: P_{opt} : compensation payment arising

Table 1

Recommended vs. observed spacing and density of fruit trees in the selected agroforestry systems in the study area (N = 210).

Agroforestry system	Recommended spacing				Recommended fruit tree density (trees/ha)	Observed fruit tree density (trees/ha)	Difference recommended minus observed fruit tree density (trees/ha)
	[C]	[S]	[M]	[N]			
[C+S]	3 * 3 m (1111)	12 * 12 m (70)	//	//	70	32	38***[4.544]
[C+M]	3 * 3 m (1111)	//	12 * 12 m (70)	//	70	55	15***[3.289]
[C+N]	3 * 3 m (1111)	//	//	25 * 25 m (16)	16	13	3*[1.620]
[C+S+M]	3 * 3 m (1111)	17 * 17 m (35)	17 * 17 m (35)	//	70	49	21***[2.796]
[C+S+N]	3 * 3 m (1111)	12 * 12 m (70)	//	25 * 25 m (16)	86	35	51** [2.265]
[C+M+N]	3 * 3 m (1111)	//	12 * 12 m (70)	25 * 25 m (16)	86	60	26***[3.067]
[C+S+M+N]	3 * 3 m (1111)	17 * 17 m (35)	17 * 17 m (35)	25 * 25 m (16)	86	53	33***[5.645]

Notes: ***, **, *: Significant at 1%, 5%, 10%

[]: t-value (); Recommended species' density

[C]=Cocoa; [S]=Safout; [M]=Bush mango; [N]=Ndjansang.

from the negotiated compromise; P_{max} : compensation payment while shifting from cocoa monoculture to cocoa agroforestry; P_{min} : compensation payment at the beginning of the negotiation; P_{sim} : compensation payment arising from policy instrument; and the received payment by cocoa cropper was denoted as P'_{sim} . In the same Equations, the density of fruit trees (in trees/ha) are symbolized as Q_{sim} : simulated number of fruit trees resulting from any policy intervention; Q_{min} : minimum number of planted fruit trees to engage in negotiation; Q_{opt} : optimal density of fruit trees at the socially efficient agroforestry point (trees/ha).

3.4. Scenarios for policy simulation

A number of market-based and regulatory policy instruments are available to enhance the adoption of agroforestry. The Government of Cameroon under its current Vision 2035 aims to promote sustainability certification for cocoa producers, and payments for ecosystem services among other objectives (Ngwasiri et al., 2002; Nchunu and Bih, 2009; Dkamela, 2011; Minepat Ministère du Plan et de l'Aménagement du Territoire, 2013; Ngwome and Tamasang, 2018; Minader Ministère de l'Agriculture et du Développement Rural, 2018). Such interventions potentially alter the structure and level of benefits generated from current forms of land use. We aim to capture these changes in a simulation analysis considering the following scenarios: cocoa sustainability certification (scenario 1), payment from voluntary carbon projects (scenario 2), and land tenure reform (scenario 3). These policy instruments are potentially suited to enhance the adoption of agroforestry and conform to current governmental strategies. We are particularly interested in outcomes with regard to the optimal fruit tree density, net social benefit and welfare gain for cocoa croppers and fruit producers in cocoa agroforestry systems, and comparing these with the optimum computed for the base case.

3.4.1. Cocoa sustainability certification (Sc.1)

Sustainability certification aims to improve the environmental, social and economic performance of agricultural value chains by giving producers who conform to defined sustainability standards the opportunity to differentiate from competition in a market increasingly driven by health and environmentally conscious consumer decisions. While several certification schemes exist for sustainable cocoa production, the Rainforest Alliance scheme was chosen for this study because it dominates the sector in Cameroon (SAN Sustainable Agricultural Network, 2008; Ngwack, 2017). Only 3% of the national cocoa production is currently certified, with Rainforest Alliance covering two thirds of this amount (Mbougha, 2015; Ngwack, 2017). The increase of the share of certified cocoa envisioned by the Government of Cameroon will hinge

on a massive expansion of cocoa agroforestry.

To motivate sustainable cocoa production practices, the Rainforest Alliance pays a price premium of between 70 and 100 FCFA per kg (Jagoret et al., 2019) to cocoa croppers who grow a minimum of 12 shade trees/ha in their cocoa orchards. Hence, this scenario assumes that a price of 1,100 FCFA/kg for certified cocoa will shift the marginal benefit (MB) curve of the cocoa cropper (Table A4), thereby influencing the optimal number of planted fruit trees on the shared land (McCloskey, 1998; Wener, 2011; Jaza, 2014). We assume that the cocoa cropper would only benefit from the price premium for cocoa, while the benefits from selling the fruits will exclusively remain with the fruit tree grower.

3.4.2. Payment from voluntary carbon projects (Sc.2)

Voluntary carbon projects aim to reduce, sequester or avoid carbon emissions via selling carbon offsets generated to buyers who can claim these against their own carbon emissions (Nchunu and Bih, 2009; Egbe and Tabot, 2011; Mbosso, 2011). Agroforestry represents one of several project types that qualify for carbon emission reductions. While the validation and verification of the carbon offset by such projects remains challenging, it is hoped that such payments can motivate farmers to preserve and/or increase the carbon stock within their ecosystems (Nchunu and Bih, 2009; Cotula and Mayers, 2009; Dkamela, 2011; Magne et al., 2014; Ngwome and Tamasang, 2018). Also in this case, we exclude any further benefits from fruit tree growing besides carbon payments and assume that benefits from selling fruits will exclusively remain with the fruit tree grower.

Previous studies from Cameroon reported carbon stocks of 80 tC/ha and sequestration rates of 2 tC/ha*year for cocoa plantations, while the fruit tree species Bush mango, Safout and Ndjansang reached carbon stocks of 324.75 tC/ha (8.11 tC/ha*year), 344.91 tC/ha (8.62 tC/ha*year), and 380 tC/ha (9.51 tC/ha*year), respectively (Mbosso, 2011; Egbe and Tabot, 2011; see also Table A1). We used these values along with an average selling price for carbon offsets of 20 USD/tC i.e. 12,000 FCFA/tC in our scenario (Awe et al., 2019). We assume that these carbon payments would shift the cocoa cropper's marginal cost curve i.e. fruit producer's marginal benefit curve (Table A4), influencing the optimal number of planted fruit trees on the shared land (Jaza, 2014).

3.4.3. Reform of the current customary tenure system (Sc.3)

While land reform and titling programs that formalize customary rights into statutory titles improve incentives for smallholders to adopt agroforestry, customary institutions too, can provide tenure security (Van Leeuwen, 2014). Crop-share arrangements between cocoa croppers and fruit producers in Cameroon have been proposed to formalize their

Table 2
Frequency, size and age of selected agroforestry systems (N = 210).

Agroforestry system	Frequency		Farm size		Average age (years)
	Count	% in study area	Average per farmer (ha)	% in study area	
[C+S]	63	30	3.2 ± 1.9	26	C 19 ± 3 S 14 ± 1
[C+M]	52	25	2.7 ± 2.5	24	C 21 ± 4 M 12 ± 1
[C+N]	32	15	2.4 ± 1.7	18	C 20 ± 2 N 13 ± 1
[C+S+M]	19	9	1.2 ± 0.9	10	C 25 ± 5 S 10 ± 3 M 10 ± 2
[C+S+N]	14	7	1.0 ± 0.7	9	C 24 ± 6 S 10 ± 3 N 10 ± 2
[C+M+N]	20	9	1.2 ± 0.8	8	C 23 ± 6 M 11 ± 2 N 11 ± 3
[C+S+M+N]	10	5	0.5 ± 0.1	5	C 27 ± 7 S 9 ± 4 M 9 ± 3 N 9 ± 4
TOTAL or AVERAGE	TOTAL: 210	TOTAL: 100 ($\chi^2 = 16.668$; P = 0.000)***	AVERAGE: 2.31	TOTAL: 100 ($\chi^2 = 7.386$; P = 0.025)**	// AVERAGE: C:23 S:11M:11N:11

Notes: ±standard deviation; [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang; ***, **: significant at 1% and 5%, respectively.

respective customary rights (Ngwasiri et al., 2002; Dkamela, 2011; Magne et al., 2014; Jaza et al., 2015; Kahler, 2018). Yet, such agreement would only be acceptable to the cocoa cropper, if the fruit producer at least compensated the cocoa cropper for the drop in revenue caused by agroforestry adoption (i.e. opportunity costs). The necessary compensation payments range from 111,000 to 310,000 FCFA/ha, corresponding to 12–47% of the fruit producer's revenue, depending on the agroforestry system (Table A4). As above, we excluded any other benefits and assume that only the revenue from fruit production is shared under this arrangement. From the range of options, we assessed two sub-scenarios that were perceived as fair by both stakeholder groups: Compensating the cocoa cropper's foregone revenue (Sc. 3a); and equally sharing the fruit revenue between both parties (Sc.3b). The compensation payments were added to the baseline MB and subtracted from MC accordingly. The subsequent MB and MC curves (Table A5)

served to compute the optimal number of fruit trees for each agroforestry system.

4. Results and discussion

4.1. Field survey findings

4.1.1. Structure of cocoa cropping systems

The fruit tree densities in cocoa agroforestry arrangements recommended by ICRAF varied between 16; 35; 70 and 1,111 trees per hectare for Ndjansang, Bush mango, Safout and Cocoa, respectively (Table 1). However, the tree densities observed in the field were lower (between 13 and 60 trees/ha) at statistically significant levels. Even if the number of trees planted originally followed ICRAF recommendations, tree losses might have been caused in the meantime by pests and diseases, bush fire

Table 3
Comparison of the cocoa cropper's and fruit producer's yield and revenue in the selected agroforestry systems (N = 210).

Agroforestry system	Density of fruit trees (trees/ha)	Yield of fruit producers (kg/ha)	Revenue of fruit producers [#] (FCFA/ha)	Yield of cocoa croppers (kg/ha)	Revenue of cocoa croppers* (FCFA/ha)
[C+S]	32 ± 52	747 ± 301	448,200 ± 240,563	296 ± 44	296,000 ± 44,354
[C+M]	55 ± 53	364 ± 208	910,000 ± 520,084	298 ± 44	298,000 ± 44,275
[C+N]	13 ± 25	351 ± 191	280,800 ± 152,466	278 ± 63	278,000 ± 63,288
[C+S+M]	[S] 25 ± 27	378 ± 214	226,800 ± 128,886	133 ± 49	133,000 ± 24,621
	[M] 24 ± 26	168 ± 98	420,000 ± 244,964		
	[S+M] 49 ± 53	//	646,800 ± 307,551		
[C+S+N]	[S] 28 ± 26	672 ± 361	403,200 ± 216,713	128 ± 52	128,000 ± 24,656
	[N] 7 ± 7	316 ± 173	252,800 ± 138,070		
	[S+N] 35 ± 33	//	656,000 ± 354,015		
[C+M+N]	[M] 40 ± 26	328 ± 187	819,375 ± 468,708	117 ± 25	117,000 ± 24,624
	[N] 20 ± 7	316 ± 173	252,800 ± 138,200		
	[M+N] 60 ± 33	//	1,072,175 ± 537,162		
[C+S+M+N]	[S] 23 ± 13	571 ± 307	342,792 ± 184,200	99 ± 16	99,000 ± 15,637
	[M] 24 ± 13	143 ± 83	357,500 ± 208,674		
	[N] 6 ± 3	300 ± 164	240,000 ± 130,859		
	[S+M+N] 53 ± 30	//	940,292 ± 365,277		

Notes: Values represent average ± standard deviation;

[#]Fruit revenues are computed by using yearly average risk-adjusted price of fruits sales as follows: 600 FCFA/kg for Safout; 2,500 FCFA/kg for Bush mango; and 800 FCFA/kg for Ndjansang (see standard deviations indicating high variance of prices in Table A1 in the Appendix).

*Cocoa revenues are computed by using the current cocoa price of 1,000 FCFA/kg. For comparison, yield and revenues amount to respectively 409 kg/ha and 409,000 FCFA/ha in cocoa mono-cropping.

[C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang.

1 Euro = 656 FCFA; 1 USD = 580 FCFA.

Table 4

Baseline solution indicating fruit tree density, marginal benefit, marginal cost and net social benefit at different negotiation points.

Agroforestry system		[C+S]	[C+M]	[C+N]	[C+S+M]	[C+S+N]	[C+M+N]	[C+S+M+N]
Zero agroforestry point	Q ₀ (trees/ha)	0	0	0	0	0	0	0
	MB or P _{max} (FCFA/tree)	30,000	125,000	37,600	77,500	31,520	107,520	69,520
	MC (FCFA/tree)	-1,112	-1,112	-576	-1,112	-1,106	-1,106	-1,679
Minimum agroforestry point	Q _{min} (trees/ha)	2	2	1	2	2	2	3
	MB or P _{min} (FCFA/tree)	29,143	121,429	35,520	75,286	30,787	105,020	67,095
	MC (FCFA/tree)	0	0	0	0	0	0	0
Socially efficient agroforestry point	Q _{opt} (trees/ha)	32	54	13	47	35	60	52
	P _{opt} or MB or MC (FCFA/tree)	16,457	28,829	6,940	25,167	18,514	32,201	27,444
	NSB (FCFA/tree)	15,327	62,867	19,135	39,507	16,508	54,515	31,644
	NSB (FCFA/ha)	490,472	3,394,829	248,753	1,856,840	577,789	3,270,919	1,645,502
Maximum agroforestry point	Q _{max} (trees/ha)	70	70	16	70	86	86	86
	MB (FCFA/tree)	0	0	0	0	0	0	0
	MC (FCFA/tree)	37,804	37,804	8,641	37,804	46,440	46,440	46,440

Notes: Q₀: full-sun system, no fruit trees planted on shared land; Q_{min}: minimum number of planted fruit trees to engage any negotiation; Q_{opt}: optimal fruit tree density arising from compromise; Q_{max}: fruit tree density maximizing the benefit of fruit producer; P_{min}: compensation payment by fruit producer at the beginning of negotiation; P_{opt}: compensation payment by fruit producer arising from negotiated compromise; P_{max}: compensation payment by fruit producer while shifting from cocoa monoculture to cocoa agroforestry; MB: marginal benefit; MC: marginal cost; NSB: net social benefit; NSB (in FCFA/ha) = NSB (in FCFA/tree)*Q_{opt}. [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang; 1 Euro = 656 FCFA; 1 USD = 580 FCFA.

or improper care and tree management (Degrande et al., 2006; Jagoret et al., 2006, 2019).

The investigated cocoa agroforestry systems were characterized by a multi-storey vertical structure. The fruit tree species formed distinct crown layers above the cocoa plants, providing a crown cover of 30–40% with optimal shade conditions (Jagoret et al., 2008). Details about the contribution of each tree species to shading conditions as a function of their height and spacing are presented in Table A2. Overall, these conditions conformed to the standards set by the Rainforest Alliance and the Sustainable Agriculture Network (SAN), which recommend at least 40% of shade, minimum 12 shade trees/ha, at least 2 strata of tree crowns and 15.8 m spacing distance between fruit trees and/or cocoa plants (SAN Sustainable Agricultural Network, 2008; Gockowski et al., 2013).

4.1.2. Extent and age of the selected agroforestry systems

The more complex quadruple/triple species agroforestry systems were less common in the field compared to two-species combinations (Table 2), which might partially be explained by environmental factors such as soil fertility or slope making some plots more suitable for multi-species agroforestry (Jaza et al., 2015). The data also showed that the fruit trees in triple and quadruple-species agroforestry systems were younger than in double species systems. While this may be related to the general reticence of farmers to engage in cocoa agroforestry (Nkamleu and Manyong, 2005), it may also suggest some degree of learning and experimentation on the farmer's side, who seemed to have adopted less complex agroforestry systems first and planted triple/quadruple-species combinations only after earlier plantings had proven successful. With an average age of 23 years cocoa trees were more than twice as old as the fruit trees. This confirms findings reported by Jagoret et al. (2019) and illustrates that ICRAF's fruit trees domestication campaign primarily addressed farmers growing cocoa in the full-sun production system.

Occupying 26% of the studied land area [C+S] appeared to be the most frequent agroforestry system in the field (Table 2). Fruit producers seemed to prefer Safout due to its regular revenue, as Safout fruits can be harvested from April to December with the peak season in July/August (Jagoret et al., 2019). Because Bush mango fruits generated total revenues up to two or three times higher than those for Safout and Ndjansang, respectively, agroforestry systems involving Bush mango were the second-most frequent system occupying 24% of the land area. Chi-Square independence tests confirmed that the differences observed between the agroforestry systems were statistically significant.

4.1.3. Yield and revenue to cocoa and fruit producers in the selected agroforestry systems

From the field data, yield and revenue of cocoa croppers and fruit producers were computed for each agroforestry system (Table 3). These results could be compared to the average cocoa yield and revenue in the monoculture system of 409 kg/ha, and 409,000 FCFA/ha, respectively. Given the simple production methods, cocoa yields only reached 41–49% of yield obtained under optimal management conditions (Degrande et al., 2007; Jagoret et al., 2008). These findings conform to Eboutou (2010) who found an average cocoa yield of 483 kg/ha for full-sun cocoa production in the study region, and Gockowski et al. (2013) who reported a yield of 503 kg/ha for extensive full-sun cocoa production in Ghana.

Table 3 also confirms that cocoa yields were lower in the agroforestry systems compared to the full-sun system. However, the total combined revenue to both parties exceeded the revenue from cocoa monocropping for all agroforestry systems. The fruit producers' revenue varied depending on the fruit tree species used, resulting from their specific yield and price of fruits. In all combinations, the fruit producers earned revenues ranging between 280,800 and 1,072,175 FCFA/ha, which was in line with results reported by Eboutou (2010) and Jaza et al. (2015) from the same region of Cameroon.

Compared to cocoa mono-cropping, the yield and revenue of cocoa croppers were reduced by almost 40% in double-species agroforestry ([C+S], [C+M], [C+N]), by 70% in triple-species ([C+S+M], [C+S+N], [C+M+N]), and by 80% in quadruple-species combinations ([C+S+M+N]) (Table 3). However, a statistically significant difference between these combinations does not exist ($\chi^2 = 2.013$ and $P = 0.733$ for double species and $\chi^2 = 2.418$, $P = 0.659$ for triple-species agroforestry).

Fruit producers recorded higher revenues than cocoa croppers in all systems. Combinations with Ndjansang, due to lower tree densities, generated lower revenues to fruit producers, whereas higher tree densities and hence revenues were observed for any combinations involving Bush mango and Safout (Tables 1 and 3).

Our results largely confirm findings by Gockowski et al. (2013) according to which cocoa yield was 78% of the full-sun system under moderate shade (34 trees/ha), while it was only 50% under heavy shade (68 trees/ha). Minang et al. (2012) found that moderate shade (30–40%) would optimize cocoa yield, while tree cover beyond 30–40% as in multi-storey cocoa systems decreases cocoa yield. Given the higher combined productivity of the agroforestry systems compared to cocoa mono-cropping, there seems to exist sufficient scope for compensating cocoa croppers for their foregone revenues.

Table 5
Optimal density of fruit trees, net social benefit and welfare gain by each farmer's category under the baseline and simulated scenarios (Sc.1 to 3).

	Agroforestry system	Baseline solution	Sc.1: Cocoa certification	Sc.2: Carbon payments	Sc.3: Tenure reform	
					Sc.3a: Zero opportunity cost	Sc.3b: Equal benefit sharing
Optimal fruit tree density Q_{opt} or Q_{sim} (trees/ha)	[C+S]	32	33	33	34	43
	[C+M]	54	55	55	55	61
	[C+N]	13	14	14	14	14
	[C+S+M]	47	49	48	52	56
	[C+S+N]	35	38	37	43	50
	[C+M+N]	60	62	61	64	71
	[C+S+M+N]	52	54	53	58	65
Net social benefit (NSB) (FCFA/ha)	[C+S]	490,472	510,860	541,728	589,526	984,808
	[C+M]	3,394,829	3,464,298	3,459,360	3,880,000	5,742,831
	[C+N]	248,753	283,175	266,418	390,355	398,325
	[C+S+M]	1,856,840	1,922,007	1,919,818	2,909,959	3,278,234
	[C+S+N]	577,789	491,130	638,082	991,590	1,201,730
	[C+M+N]	3,270,919	3,363,140	2,921,899	4,404,518	5,753,595
	[C+S+M+N]	1,645,502	1,915,846	1,925,543	2,726,566	3,427,350
Gain for cocoa cropper compared to baseline (FCFA/ha)	[C+S]	0	911	911	3,236	87,797
	[C+M]	0	2,242	2,242	6,242	29,252
	[C+N]	0	2,569	2,569	8,879	35,890
	[C+S+M]	0	5,089	1,160	33,498	110,156
	[C+S+N]	0	5,153	2,148	49,350	141,593
	[C+M+N]	0	5,660	1,304	23,532	182,254
	[C+S+M+N]	0	4,289	1,057	38,979	183,463
Gain for fruit producer compared to baseline (FCFA/ha)	[C+S]	0	15,843	15,843	15,414	127,083
	[C+M]	0	26,770	26,770	26,770	112,378
	[C+N]	0	4,700	4,700	16,900	114,700
	[C+S+M]	0	46,514	24,364	99,680	139,572
	[C+S+N]	0	52,722	35,882	157,390	197,550
	[C+M+N]	0	60,040	31,270	110,080	206,470
	[C+S+M+N]	0	51,776	26,696	135,936	221,000

Notes: Sc.1: Cocoa sustainability certification; Sc.2: Payments for voluntary carbon projects; Sc.3: Tenure reform (Sc.3a: Compensating the cocoa croppers' foregone revenue; Sc.3b: Equally sharing the revenue between cocoa croppers and fruit producers); Q_{opt} : Optimal fruit tree density arising from compromise; Q_{sim} : Simulated number of fruit trees resulting from any policy intervention/scenario; [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang; 1 Euro = 656 FCFA; 1 USD = 580FCFA.

4.2. Socially efficient cocoa agroforestry point and related net social benefit according to the baseline solution

We constructed the TB and TC curves for the baseline model, representing the total benefit and total cost of compensation by the fruit producer, from our field data according to the procedure described in Appendix 2. As cocoa croppers are currently not compensated for externalities caused by fruit tree growers in existing agroforestry arrangements, the baseline result suggests the optimal solution from the Coase theorem for the negotiation between both parties with regard to converting additional full-sun cocoa orchards into agroforestry. In most cases this solution was similar to the field survey findings in terms of fruit trees density and yield (Table 3), confirming thereby the validity of the Coase theorem model (Coase, 1960; Hahnel and Sheeran, 2009; Jaza, 2014).

For each agroforestry combination we computed the socially efficient agroforestry point (Q_{opt}) denoting the level of agroforestry acceptable to both parties. Assuming that each party aims to maximize their profits, a compromise would be achieved at the point where the marginal benefits of the two parties are equal. Solving the equation $MB=MC$ gave $Q_{opt} = 32; 54; 13; 47; 35; 60;$ and 52 trees/ha respectively for the [C+S], [C+M], [C+N], [C+S+M], [C+S+N], [C+M+N] and [C+S+M+N] agroforestry systems (Table 4). These baseline results were also confirmed by Jagoret et al. (2006) who counted 10–155 fruit trees/ha in cocoa agroforestry systems of the study region.

Our results imply that the fruit producer and cocoa cropper are satisfied when the tree density ranges between 13 and 60 per hectare, depending of the agroforestry system. The corresponding benefit and/or cost at the socially efficient agroforestry point, which was calculated by plugging the socially efficient production point Q_{opt} into either the marginal benefit (MB) or marginal cost (MC) functions, gave the compensation payment P_{opt} of $MB = MC = 16,457; 28,829; 6,940;$

25,167; 18,514; 32,201; and 27,444 FCFA/ha respectively for the [C+S], [C+M], [C+N], [C+S+M], [C+S+N], [C+M+N] and [C+S+M+N] agroforestry systems (Table 4; Fig. 1). In general, agroforestry systems with a higher optimal fruit tree density Q_{opt} also had a higher compensation payment P_{opt} (Table 4).

Comparing the various agroforestry systems, the socially efficient agroforestry point Q_{opt} was reduced in all combinations with Ndjansang. The lowest Q_{opt} (13 trees/ha) was obtained in the [C+N] combination (Table 4). This was due to the low value of Ndjansang fruits and the fact that the revenues from selling these fruits cannot compensate for higher reductions in cocoa production that occur at higher tree densities. However, this analysis disregards any environmental benefits associated with Ndjansang trees, such as a comparatively larger biodiversity value than Bush mango or Safout trees (Costanza et al., 1997; Arowolo et al., 2018; Tolessa et al., 2018).

Table 4 also presents the net social benefit (NSB) for each of the selected agroforestry systems. The results showed that agroforestry systems with the largest number of fruit trees at the socially efficient (Q_{opt}) point also had the highest NSB, proving that encouraging fruit tree planting in cocoa agroforestry would be socially profitable. On the basis of their social preference (NSB), the agroforestry systems can be ranked from high to low as follows: [C+M], [C+M+N], [C+S+M], [C+S+M+N], [C+S+N], [C+S] and [C+N]. The top four most socially desirable agroforestry systems involve Bush mango due to their highly valuable fruits. Hence, fruit producers should preferably engage in negotiations with cocoa croppers for the purpose of Bush mango production.

Table 4 illustrates that ICRAF's recommended tree densities corresponded well with the maximum agroforestry point (Q_{max}) computed for each system. This suggests that ICRAF's recommendations reflected an agronomic rather than the economic optimum under the locally prevailing customary land tenure conditions. In contrast, the socially

efficient agroforestry point (Q_{opt}) proposes tree densities that are between 19% (for [C+N]) and 59% (for [C+S+N]) lower than originally recommended by ICRAF to balance the cocoa cropper's declining net revenues with the fruit producer's benefits using the currently prevailing cost and price levels.

Likewise, the spatial extent of agroforestry combinations does not correspond to their respective social preference. While the two agroforestry systems most socially beneficial ([C+M] and [C+M+N]) occur on only 32% of the total area, the systems that generate the lowest net social benefits ([C+S+N], [C+S] and [C+N]) cover 53% of the area (Tables 2, 4 and 5). Moreover, as shown by Jaza et al. (2015) the financial performance of these more frequently prevailing systems is only mediocre to poor compared to the more socially beneficial ones (Table A6). These facts suggest that a largely agro-technical rather than welfare-oriented approach has been taken to designing and disseminating agroforestry systems in the study region in the past, which might have added to other existing adoption barriers. This illustrates the significant potential that exists with regard to further improving these systems.

4.3. Simulated results from various policy instruments

4.3.1. Cocoa sustainability certification (Sc. 1)

As revealed by Table 5, cocoa certification would encourage farmers to plant more fruit trees as compared to the baseline, generating additional income for cocoa croppers (911–5,660 FCFA/ha) and fruit producers (4,700–60,040 FCFA/ha) as well as increase the net social benefit. Given that, in principle, both cocoa croppers and fruit tree growers could claim the additional benefits from the cocoa certification premium, we investigated how a varying distribution of the premium payment between both parties would affect the acceptability of agroforestry to the cocoa cropper (Fig. A1 in Appendix 1). The results of this analysis clearly indicate that, *ceteris paribus*, the current price premium for sustainably produced cocoa is too low to effectively induce the conversion of cocoa full-sun systems into agroforestry as it does not sufficiently compensate cocoa croppers for their foregone cocoa revenues. Even if the cocoa cropper would capture the entire price premium, a premium of 272–3,031 FCFA/kg (between 2.7 and 30.3 times above the current level) would be required in the various systems to attain this outcome.

4.3.2. Payment from voluntary carbon projects (Sc. 2)

Similar to scenario 1, payments from voluntary carbon projects would encourage more fruit tree planting compared to the baseline. The benefits to cocoa croppers (911–5,138 FCFA/ha), fruit producers (4,700–35,882 FCFA/ha), and the net social benefit would increase (Table 5, Sc. 2). Fruit producers can realize the highest gain in triple or quadruple-species agroforestry systems involving Ndjansang, which sequester more carbon than two-species agroforestry combinations.

Similar to the first scenario, both cocoa croppers and fruit producers could claim the carbon payment made. Fig. A2 shows how the acceptability of agroforestry to the cocoa cropper is influenced by a varying distribution of the carbon payment between both parties. The results indicate that, *ceteris paribus*, the current carbon price can effectively induce the conversion of cocoa full-sun systems into [C+S], [C+M] or [C+N] agroforestry over almost the entire benefit distribution range. However, a carbon price of 25.89–50.22 USD/t is required to compensate the cocoa cropper for her benefits forgone in the other agroforestry combinations.

4.3.3. Reform of the customary tenure system (Sc.3)

Unlike the baseline solution and scenarios 1 and 2, scenario 3 assumes that the revenue from fruit production will be shared between both parties. The results in Table 5 indicate that a reform requiring parties to equally share the fruit revenues (Sc.3b) has the strongest positive effect on additional fruit tree planting compared to a tenure

reform merely compensating the opportunity cost of the cocoa cropper (Sc.3a). The net social benefit would increase to 589,526–4,404,518 FCFA/ha (Sc.3a) and 984,308–5,753,595 FCFA/ha (Sc. 3b), also inducing additional gains to the cocoa cropper and fruit producer.

Fig. A3 shows how the acceptability of agroforestry to the cocoa cropper is influenced by the various benefit distribution arrangements of fruit revenues between both parties. The intersection points of the curves with the X-axis (at $Y = 0$) indicate that a minimum of 12.2–46.7% (for [C+M] and [C+N], respectively; cf. Table A4) of fruit revenues are required by the cocoa cropper to accept the agroforestry option. These points correspond to the compensation of the cocoa cropper's foregone cocoa revenue (Sc.3a). When fruit revenues are shared equally between both parties (at $X = 50\%$; Sc.3b), values far below the current price premium indicate that the various agroforestry systems would remain attractive for the cocoa cropper even if the cocoa price would drop considerably.

Overall, in terms of additional number of planted trees, net social benefit as well as gain for both parties, a tenure reform that facilitates a fair sharing of benefits of cocoa agroforestry between customary land and tree owners is the most effective intervention among the investigated policy instruments to promote the conversion of full-sun cocoa systems into agroforestry. This corroborates the relevance of secure tenure arrangements to promote agroforestry in the study area.

5. Conclusion and recommendations

This study aimed to investigate how agroforestry could be promoted through market-based and regulatory policy instruments in conditions of customary land tenure arrangements that separate the ownership of land and trees. In light of the apparent difficulties in implementing formal land titling programs in many parts of the global South, this is a question of high empirical relevance. Using data collected from the Centre region of Cameroon, field survey and Coase theorem baseline results indicated that land sharing between cocoa croppers and fruit producers is socially beneficial despite the fact that the revenue foregone by the cocoa cropper as a consequence of a reduced cocoa yield is not compensated by the fruit producer under the prevailing customary tenure regime. Depending on the agroforestry system, the social optimum was reached at a tree density of 13–60 trees/ha, corresponding to a net social benefit of 248,753 to 3,394,829 FCFA/ha.

Among the investigated policy instruments, a tenure reform introducing benefit sharing arrangements between both parties (Sc.3b) proved to have the largest positive effect on cocoa agroforestry adoption. Cocoa sustainability certification (Sc.1) and payment for voluntary carbon projects (Sc.2) – although increasing the number of fruit trees planted, net social benefit and welfare gain by cocoa cropper and fruit producer compared to the baseline – were less effective. Additionally, the latter policy instruments face significant challenges with regard to their short-term implementation. For example, as most certification bodies typically require proof of land ownership prior to awarding their certification, the limited number of farms currently possessing land title deeds represents a major bottleneck to the expansion of sustainability certification. Likewise, despite the fact that voluntary carbon payments are supported by various international initiatives (Lawson et al., 2002; Egbe and Tabot, 2011; Leakey, 2011; Minang et al., 2012; O'Sullivan et al., 2018), the laws and organizational structures needed for their implementation are currently lacking in Cameroon (Dkamela, 2011; Magne et al., 2014; Foundjem-Tita, 2013; Ngwome and Tamasang, 2018; Jagoret et al., 2019). Hence, the implementation of cocoa sustainability certification (Sc.1) and payments from voluntary carbon projects (Sc.2) seem less feasible in the short-term. An accelerated process of issuing legal titles to the customary owners of land and trees could support both measures. In addition, we recommend that certification bodies – at least temporarily – consider granting their certificates and payments to customary land and tree owners who can provide a testimony of undisputed ownership by the village chiefs or family heads

in lieu of formal titles (Tchamgagni, 2007; Haglung et al., 2011; Kahler, 2018; Jagoret et al., 2019).

Therefore, a tenure reform acknowledging the customary rights of cocoa croppers and fruit producers, and at the same time balancing the interests of both parties is required to further promote the adoption of cocoa agroforestry. Towards this aim, scenario 3 envisages a benefit-sharing arrangement that partially modifies the bundles of customary rights (Schlager and Ostrom, 1992) of both parties as follows: On the one hand, it limits the tree grower's withdrawal rights to compensate the cocoa cropper's losses from accepting fruit production on her farm. In return, the fruit producer would receive the management right to increase the number of fruit trees as long as it equally benefits both parties and increases social welfare. Existing customary access and exclusion rights would not be affected by the proposed tenure reform. To formalize these rights, we propose that authorities or traditional leaders issue land title certificates containing the names of both customary land and tree owners thereby embodying the traditional rights in land and trees typical in the region. However, the concrete design of such a policy and necessary steps to practical implementation were beyond the focus of our analysis. If successful, such tenure reform could be extended to other regions with separated customary ownership of land and trees, such as the forest bimodal zone in Cameroon's Centre, South and East regions in which the Ewondo, Bassa, Etong, Bulu, and Baka ethnic groups share a similar tradition of patrilineal inheritance (Dkamela, 2011; Jaza et al., 2015; Kahler, 2018).

Our analyses also show that fruit producers generally earn higher revenues than cocoa croppers. Only for the [C+N] agroforestry system, which covers approximately 18% of the total area, income of both parties is almost equal. For all investigated agroforestry systems, the combined revenues of cocoa croppers and fruit tree producers exceed the revenues generated under full-sun cocoa cultivation illustrating that cocoa agroforestry is economically more viable. Yet, our results also point at a significant potential to improve the investigated cocoa

agroforestry systems with regard to optimal tree density and species combinations to maximize net social benefit. Furthermore, low current yields compared to similar systems elsewhere suggest that considerable gains from improving management practices and use of farm inputs are possible.

Finally, the fact that many cocoa croppers in the study region have not planted fruit trees in their cocoa orchards highlights the presence of significant adoption barriers. Removing these barriers could result in an even higher net social benefit of cocoa agroforestry than computed in our study. The support of fruit production and marketing cooperatives (Degrande et al., 2007), the establishment of fruit tree nurseries and training programs for fruit tree propagation (Schreckenberget al., 2002; Place, 2009; Magne et al., 2014), the increased reliability of rural energy supply and the development of local fruit processing enterprises (Degrande et al., 2007; Minader Ministère de l'Agriculture et du Développement Rural, 2018; Jagoret et al., 2019) and an effective land registration (Firmin-Sellers and Sellers, 1999; ADB African Development Bank, 2009; Kahler, 2018) are some of the measures urgently needed to promote cocoa agroforestry in the study region. If more cocoa croppers plant agroforestry trees in their cocoa orchards, the current separation of ownership of land and trees might gradually disappear in the future. However, until this point local stakeholders and policy makers should acknowledge and respect the distinct customary rights of land owners and tree growers in their respective natural resources.

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Appendix 1

See Table A1, Table A2, Table A3, Table A4, Table A5, Table A6, Tables A7 and A8, and Table A9.

Table A1

Received prices, sold production quantity of fruits, actual fruits sales, carbon stock, sequestration rate and value for selected agroforestry species in the study area.

	Cocoa	Safout	Bush mango	Ndjansang
Received price of fruits (FCFA/kg)	1,000 ± 150	600 ± 552	2,500 ± 2,275	800 ± 728
Sold fruit production quantity per tree (kg/year)	0.54 ± 0.11	50 ± 46	50 ± 46	47 ± 43
Actual fruits revenue generated per tree (FCFA/year)	540 ± 17	30,000 ± 25,392	125,000 ± 104,650	37,600 ± 31,304
Carbon (C) stock (ton C/ha)	80 ± 2	344.91 ± 14.02	324.75 ± 9.43	380.51 ± 17.59
Carbon sequestration rate (ton C/ha/year)	2 ± 0.1	8.62 ± 0.8	8.11 ± 0.6	9.51 ± 0.9
Value of Carbon (C) sequestration (FCFA/tree/year)	//	2,069 ± 421	1,947 ± 179	2,283 ± 533

Notes:

Values represent average ± standard deviation. Actual revenue from fruits sales generated per tree = Received price * sold fruit production quantity per tree; Reward from C sequestration = C sequestration rate / Tree density * C price of 20 USD/tC; 1 Euro = 656 FCFA; 1 USD = 580 FCFA.

Source: Costanza et al. (1997); Eboutou (2010); Mbosso (2011); Egbe and Tabot (2011); Arowolo et al. (2018); Tolessa et al. (2018).

Table A2

Stratification of tree species in cocoa agroforestry systems with regard to contribution to shade, spacing and tree height.

	Contribution to shade	Spacing	Tree height
Stratum 1: [C]	68%	3 * 3 m	3–5 m
Stratum 2: [S], [M]	24%	12 * 12 m or 17 * 17 m	5–20 m
Stratum 3: [N]	8%	25 * 25 m	>20 m
TOTAL	100%	//	//

Notes: [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang

Source: Todem (2005); Jagoret et al. (2008); Eboutou (2010); Kwesseu (2010); Jaza et al. (2015)

Table A3
 Estimated coefficients for the quadratic functions of the total benefit (TB) and total cost (TC) in function of fruit tree density (Q).

Scenario	Agroforestry System	Total Benefit (TB) function				Total Cost (TC) function			
		Constant/ intercept	Q	Q ²	TOTAL	Constant/ intercept	Q	Q ²	TOTAL
Baseline	[C+S]	-292,664 (-3.612)***	+30,000 (3.888)***	-214 (-5.070)***	R ² = 0.788 F = 177.15	46,912 (3.462)***	-1,112 (-6.568)***	+278 (7.819) ***	R ² = 0.696 F = 197.09
	[C+M]	-3,236,012 (-1.741)*	+125,000 (8.986)***	-893 (-8.245)***	R ² = 0.682 F = 113.94	-452,600 (-3.462)***	-1,112 (-4.568)***	+278 (5.819) ***	R ² = 0.696 F = 197.09
	[C+N]	-9,425 (-2.813)***	+37,600 (12.830)***	-1,175 (-11.288) ***	R ² = 0.888 F = 213.07	236,816 (2.753)***	-576 (-2.617)***	+288 (2.553) ***	R ² = 0.975 F = 164.33
	[C+S+M]	-1,771,914 (-1.896)*	+77,500 (2.434)**	-554 (-1.945)*	R ² = 0.588 F = 113.07	-428,838 (-2.462)***	-1,112 (-9.568)***	+278 (8.819) ***	R ² = 0.696 F = 197.09
	[C+S+N]	-223,025 (-1.741)*	+31,520 (1.667)*	-183 (-2.23) * *	R ² = 0.778 F = 144.56	-172,615 (-2.493)**	-1106 (-1.995)*	+277 (2.891) ***	R ² = 0.865 F = 202.03
	[C+M+N]	-3129,025 (-2.444)**	+107,520 (3.255)***	-625 (-7.444)* **	R ² = 0.679 F = 178.09	-810,240 (-2.049)**	-1106 (1.995)*	+276 (2.891) ***	R ² = 0.865 F = 202.03
	[C+S+M+N]	-1,582,332 (-4.255)***	+69,520 (10.545)***	-404 (-2.961)* **	R ² = 0.597 F = 186.03	-570,812 (1.897)*	-1679 (-2.372)**	+280 (1.786)*	R ² = 0.611 F = 165.55
Cocoa sustainability certification (Sc.1)	[C+S]	-308,754 (-1.612)*	+30,000 (1.804)*	-214 (-2.010)* *	R ² = 0.532 F = 178.80	59,357 (3.453)***	-1112 (-2.344)***	251 (2.212)**	R ² = 0.478 F = 188.9
	[C+M]	-3263,675 (-2207)**	+125,000 (3.019)***	-893 (-1.767)*	R ² = 0.499 F = 134.87	-400,115 (-3.344)***	-1112 (-2.453)**	+251 (1890)*	R ² = 0.789 F = 223.08
	[C+N]	-15,300 (-3.209)***	+s)***	-1175 (-1677)*	R ² = 0.754 F = 199.89	234,908 (4.343)***	-576 (-2.233)**	+261 (3.344) ***	R ² = 0.751 F = 209.78
	[C+S+M]	-1,820,546 (-1.567)*	+77,500 (1.767)**	-554 (-3.342)* **	R ² = 0.675 F = 213.09	-415,163 (-6.344)***	-1112 (-3.344)***	+251 (4.343) ***	R ² = 0.523 F = 177.6
	[C+S+N]	-277,508 (-2.453)**	+31,520 (3.567)***	-183 (-2.767)* **	R ² = 0.543 F = 176.76	-190,972 (-1.457)	-1106 (-2.344)**	+250 (4.566) ***	R ² = 0.665 F = 223.03
	[C+M+N]	-3,191,565 (-4.207)***	+107,520 (1.876)*	-625 (-2675) * **	R ² = 0.677 F = 186.90	-775,428 (-1.107)	-1106 (-1.233)	+250 (2.787) ***	R ² = 0.665 F = 222.03
	[C+S+M+N]	-1,635,724 (-3.453)***	+69,520 (2.239)**	-404 (-3.445)* **	R ² = 0.645 F = 175.87	-548,082 (-1.998)**	-1679 (-2.344)**	+253 (3.456) ***	R ² = 0.515 F = 168.59
Payment for voluntary carbon projects (Sc.2)	[C+S]	-859,458 (-3.444)***	+32,069 (3.455)***	-229 (-2.213)* *	R ² = 0.786 F = 218.54	29,954 (3.876)***	-1112 (0.3444)***	+278 (3.334) ***	R ² = 0.677 F = 156.89
	[C+M]	-8815,760 (-1.232)	+126,947 (2.455)**	-907 (-2.454)* *	R ² = 0.786 F = 187.99	-481,790 (-2.454)**	-1112 (-2.209)**	+278 (2.923) ***	R ² = 0.543 F = 167.97
	[C+N]	-521,974 (-2.455)**	+39,883 (1.777)*	-1247 (-1.987)*	R ² = 0.675 F = 187.24	229,616 (3554)***	-576 (-1.998)*	+288 (3565)***	R ² = 0.776 F = 200.34
	[C+S+M]	-4478,256 (-3.245)***	+79,508 (3.455)***	-568 (-2.453)* *	R ² = 0.756 F = 221.05	-454,136 (-2.899)***	-1112 (-3.444)***	+278 (2.889) ***	R ² = 0.654 F = 199.06
	[C+S+N]	-856,708 (-2.565)**	+33,632 (4.345)***	-196 (-3.444)* **	R ² = 0.712 F = 168.90	-210,291 (-3.911)***	-1106 (-2.454)**	+277 (3.656)**	R ² = 0.634 F = 187.98
	[C+M+N]	-7979,676 (-1.766)*	+109,534 (3.454)***	-637 (-3.565)* **	R ² = 0.508 F = 167.98	-846,251 (-4.328)***	-1106 (-1.676)*	+277 (4.414) ***	R ² = 0.867 F = 198.76
	[C+S+M+N]	-4022,151 (-3.344)***	+71,583 (1.676)*	-416 (-1.786)*	R ² = 0.709 F = 189.94	-598,533 (-3.564)***	-1679 (-3.232)***	+280 (2.454)**	R ² = 0.809 F = 176.54
Land Reform: Zero opportunity cost (Sc.3a)	[C+S]	-418,800 (-1.742)*	+33,660 (2.451)**	-240 (-1.786)*	R ² = 0.762 F = 214.75	+12,440 (1.067)	-1112 (-3.004)***	+278 (1.978)*	R ² = 0.589 F = 167.01
	[C+M]	-3765,000 (-1.412)	+140,000 (1.789)*	-1000 (-1.987)*	R ² = 0.713 F = 185.08	-481,790 (1.897)*	-1112 (-2.067)**	+278 (2.344)**	R ² = 0.696 F = 195.02
	[C+N]	-154,516 (-2.131)**	+55,272 (2.345)**	-1727 (-2.987)***	R ² = 0.617 F = 177.94	+229,616 (2.456)**	-576 (-1.786)*	+288 (3.005) ***	R ² = 0.875 F = 174.78
	[C+S+M]	-2977,236 (-1.239)	+110,825 (3.063)***	-791 (-2.231)**	R ² = 0.769 F = 212.08	-560,888 (-3.071)***	-1,112 (-2.781)***	+278 (2.455)**	R ² = 0.689 F = 177.01
	[C+S+N]	-797,744 (-2.789)***	+45,074 (2.879)***	-262 (-1.978)*	R ² = 0.716 F = 170.01	-336,615 (-1.799)*	-1,106 (-1.878)*	+277 (1.897)*	R ² = 0.768 F = 198.03
	[C+M+N]	-4414,801 (-1.045)	+136,550 (1.876)*	-794 (-2.314)**	R ² = 0.515 F = 170.98	-946,808 (-2.089)**	-1,106 (-2.324)**	+277 (1.786)*	R ² = 0.799 F = 198.09
	[C+S+M+N]	-2616,036 (-1.306)	+92,462 (2.143)**	-537 (3.004) ***	R ² = 0.722 F = 199.12	-745,538 (-2.268)**	-1679 (-1.898)*	+280 (2.453)**	R ² = 0.689 F = 198.09

(continued on next page)

Table A3 (continued)

Scenario	Agroforestry System	Total Benefit (TB) function				Total Cost (TC) function			
		Constant/ intercept	Q	Q ²	TOTAL	Constant/ intercept	Q	Q ²	TOTAL
Tenure Reform: Equal benefit sharing (Sc.3b)	[C+S]	-891,422 (-1.123)	+45,000 (3.665)***	-322 (-2.333)**	R ² = 0.606 F = 123.09	275,102 (1.105)	-16,112 (-2.409)**	+386 (3.216)***	R ² = 0.767 F = 134.89
	[C+M]	-5545,081 (-2.334)**	+187,500 (4.234)***	-1339 (-3.434)***	R ² = 0.542 F = 134.45	1,480,607 (1.256)	-63,612 (-3.456)***	+725 (2.767)***	R ² = 0.744 F = 147.09
	[C+N]	-163,448 (-1.453)	+56,400 (3.444)***	-1762 (-2.434)**	R ² = 0.785 F = 234.98	377,568 (3.509)***	-19,376 (-4.234)***	+876 (1.787)*	R ² = 0.607 F = 178.09
	[C+S+M]	-3260,320 (-2.978)***	+116,250 (2.314)**	-830 (-3.453)***	R ² = 0.672 F = 123.98	624,792 (2.407)**	-39,862 (-2.344)**	+555 (1.675)*	R ² = 0.778 F = 175.67
	[C+S+N]	-1,020,500 (-2.786)***	+47,280 (3.765)***	-275 (-4.244)***	R ² = 0.564 F = 123.87	48,800 (1.768)*	-16,866 (-3.443)***	+369 (2.005)**	R ² = 0.785 F = 156.09
	[C+M+N]	-5,655,288 (-1.786)**	+161,280 (1.989)**	-937 (-3.445)***	R ² = 0.564 F = 145.98	1,043,337 (1.023)	-54,866 (-2.348)**	+589 (2.989)***	R ² = 0.654 F = 165.08
	[C+S+M+N]	-3,277,558 (-1.457)	+104,280 (2.453)**	-606 (-2.345)**	R ² = 0.786 F = 223.09	431,085 (3.543)***	-36,439 (-3.675)***	+482 (3.002)***	R ² = 0.608 F = 134.44

Notes: Sc.=Scenario; [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang.

***, **, *: Significant at 1%, 5%, 10%; () : t-value.

Table A4

The cocoa cropper's and fruit producer's revenue from agroforestry and the necessary compensation to cover the cocoa cropper's opportunity cost.

Agroforestry system	Cocoa cropper's total revenue under agroforestry system (FCFA/ha)	Cocoa cropper's foregone revenue compared to cocoa mono-cropping (FCFA/ha)	Fruit producer's total revenue (FCFA/ha)	Share of fruit producer's revenue to be compensated to the cocoa cropper (%)
[C+S]	296,000	113,000	448,200	25.21
[C+M]	298,000	111,000	910,000	12.20
[C+N]	278,000	131,000	280,800	46.65
[C+S+M]	133,000	276,000	646,800	42.67
[C+S+N]	128,000	281,000	656,000	42.84
[C+M+N]	117,000	292,000	1,072,175	27.23
[C+S+M+N]	99,000	310,000	940,292	32.97

Notes: Computed from Table 3, based on cocoa mono-cropping revenue of 409,000 FCFA/ha. 1 Euro=656 FCFA; 1 USD=580 FCFA.

Column E = Column C/ Column D. [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang.

Appendix 2. Estimating total benefit and total cost functions for the baseline model from the field data

Table A3 (Appendix 1) presents the results of the analysis when data of the cocoa mono-cropper's total benefit (TB) and total cost (TC) of compensation by the fruit producer are each regressed, using the *Ordinary Least Square* method, against the two independent variables, i.e. (1.) the density of fruit trees (Q), and (2.) the squared-density of fruit trees (Q²) planted in association with cocoa in each agroforestry system. Multicollinearity was examined through the estimation of the Variance Inflation Factors (VIF) and Pearson correlation coefficients between the two explanatory variables Q and Q² (Wooldridge, 2013). Most correlation coefficients were low and insignificant and all the VIF were below 2, indicating the absence of serious multicollinearity (Fig. A1, Fig. A2, and Fig. A3).

In the two regression functions TB = f(Q,Q²) and TC = f(Q,Q²) high coefficients of determination (R²), ranging between 0.611 and 0.975, validated the regression model. For the [C+S] combination for instance the estimated R² values indicated that 78.8% and 69.6%, respectively for the TB and TC functions was explained by the density of fruit trees (Q) and squared-density of fruit trees planted (Q²). Furthermore, each regression showed an F-value significant at the 1% level, implying that each estimated regression line fitted the data very well.

In each regression equation, all coefficients of the independent variables showed the expected signs (for both the *linear coefficient* Q and the *quadratic coefficient* Q²). Namely the TB function showed a positive sign for Q and a negative sign for Q², meaning, for example, that an additional fruit tree planted on the shared land Q would induce a positive impact on the total benefit (TB) of the fruit producer. On the other hand, the higher the squared-number of fruit trees planted on the shared land Q², the lower the total benefit (TB) of the fruit producer.

For the TC function the estimated signs were negative for Q and positive for Q². The values indicated that an additional fruit tree planted on the shared land Q would reduce the total cost (TC) of compensation by the fruit producer, whereas an additional squared-number of planted fruit trees Q² would increase the total cost (TC) of compensation by the fruit producer.

By considering for instance the [C+S] agroforestry system as baseline, the estimated quadratic total benefit (TB) and total cost (TC) functions from Table A3 (Appendix 1) are expressed in Equations (A.1) and (A.2):

$$TB = -292,664 + 30,000Q - 214Q^2 \quad (A.1)$$

$$TC = 46,912 - 1,112Q + 278Q^2 \quad (A.2)$$

By taking the first derivative of each function the mathematical formulas of the marginal benefit (MB) and marginal cost (MC) functions are expressed in Eqs. (A.3) and (A.4) as:

Table A5
Marginal benefit (MB) and marginal cost (MC) equations as function of fruit tree density (Q) under the baseline and scenario assumptions.

Scenario	Agroforestry System	Marginal Benefit (MB) function	Marginal Cost (MC) function	
Baseline	[C+S]	30,000–429Q	-1112 + 556Q	
	[C+M]	125,000–1,786Q	-1112 + 556Q	
	[C+N]	37,600–2,350Q	-576 + 576Q	
	[C+S+M]	77,500–1,107Q	-1112 + 556Q	
	[C+S+N]	31,520–367Q	-1106 + 553Q	
	[C+M+N]	107,520–1,250Q	-1106 + 553Q	
	[C+S+M+N]	69,520–808Q	-1679 + 560Q	
	Cocoa sustainability certification (Sc.1)	[C+S]	30,000–429Q	-1112 + 502Q
		[C+M]	125,000–1,786Q	-1112 + 502Q
		[C+N]	37,600–2,350Q	-576 + 522Q
[C+S+M]		77,500–1,107Q	-1112 + 502Q	
[C+S+N]		31,520–367Q	-1106 + 499Q	
[C+M+N]		107,520–1,250Q	-1106 + 499Q	
[C+S+M+N]		69,520–808Q	-1679 + 506Q	
Payment for voluntary carbon projects (Sc.2)		[C+S]	32,069–458Q	-1112 + 556Q
		[C+M]	126,947–1,814Q	-1112 + 556Q
		[C+N]	39,883–2,493Q	-576 + 576Q
	[C+S+M]	79,508–1,136Q	-1112 + 556Q	
	[C+S+N]	33,632–391Q	-1106 + 553Q	
	[C+M+N]	109,534–1,274Q	-1106 + 553Q	
	[C+S+M+N]	71,583–832Q	-1679 + 560Q	
	Tenure reform (Sc.3)	Sc.3a: Compensating the cocoa croppers' foregone revenue		
		[C+S]	33,660–481Q	-1112 + 556Q
		[C+M]	140,000–2,000Q	-1112 + 556Q
[C+N]		55,272–3,455Q	-576 + 576Q	
[C+S+M]		110,825–1,583Q	-1112 + 556Q	
[C+S+N]		45,074–525Q	-1106 + 553Q	
[C+M+N]		136,550–1,588Q	-1106 + 553Q	
[C+S+M+N]		92,462–1,075Q	-1679 + 560Q	
Sc.3b: Equally sharing revenue between cocoa croppers and fruit producers				
[C+S]		45,000–644Q	-16,112 + 771Q	
[C+M]	187,500–2,679Q	-63,612 + 1,449Q		
[C+N]	56,400–3,525Q	-19,376 + 1,751Q		
[C+S+M]	116,250–1,661Q	-39,862 + 1,110Q		
[C+S+N]	47,280–551Q	-16,866 + 737Q		
[C+M+N]	161,280–1,875Q	-54,866 + 1,178Q		
[C+S+M+N]	104,280–1,212Q	-36,439 + 964Q		

Notes: Computed from Table A3, where MB is derived by taking the first derivative over Q of the TB quadratic function whereas MC is derived by taking the first derivative over Q of the TC quadratic function. Sc. = Scenario; [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang; 1 Euro = 656 FCFA; 1USD = 580 FCFA.

Table A6
Values of Net Present Value (NPV), Internal Rate of Return (IRR), Pay-Back Period (PBP) and Benefit Cost Ratio (BCR) for different agroforestry systems.

Agroforestry system		Financial appraisal tool			
		NPV (FCFA/ha)	IRR (%)	PBP (years)	BCR
Single/None combination	[C]	-267,648	13.4	17	1.35
	[C+N]	+876,416	41.3	8	5.00
Double combination	[C+S]	+4,681,216	42.8	8	5.05
	[C+M]	+5,680,304	43.9	7	5.48
Triple combination	[C+S+N]	+6,845,360	47.4	6	6.00
	[C+M+N]	+7,658,800	48.6	5	7.10
	[C+S+M]	+12,006,768	49.3	5	7.58
Quadruple combination	[C+S+M+N]	+12,725,088	52.7	4	8.20

Notes: [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang; NPV = Net Present Value; IRR = Internal Rate of Return; PBP = Pay-Back Period; BCR = Benefit Cost Ratio. 1 Euro = 656 FCFA; 1USD = 580 FCFA.

Source: Jaza et al. (2015)

$$MB = \frac{\partial TB}{\partial Q} = 30,000 - 429Q \tag{A.3}$$

$$MC = \frac{\partial TC}{\partial Q} = -1,112 + 556Q \tag{A.4}$$

The MB and MC functions for all agroforestry systems are presented in Table A5 (Appendix 1). The estimates at baseline showed that the MB function differed for each agroforestry system. However, the MC function was similar for the [C+S], [C+M], and [C+S+M] agroforestry systems given that in these systems the same number of fruit trees were planted in the cocoa orchard.

In Eqs. (A.1)–(A.4), Q is the number of fruit trees planted on the shared land (trees/ha); TB denotes the total benefit of fruit producers (in FCFA/ha); TC represents the total cost of compensation by fruit producers (in FCFA/ha); MB is the marginal benefit of the fruit producers (in FCFA/ha); and MC denotes the marginal cost of compensation by the fruit producers (in FCFA/ha).

Table A7

Number of respondents for selected agroforestry systems in the villages (V1 to V10) surveyed in the study area.

Agroforestry system	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	Total
[C+S]	6	6	6	6	6	6	6	7	7	7	63
[C+M]	5	5	5	5	5	5	5	5	6	6	52
[C+N]	3	3	3	3	3	3	3	3	4	4	32
[C+S+M]	1	2	2	2	2	2	2	2	2	2	19
[C+S+N]	1	1	1	1	1	1	2	2	2	2	14
[C+M+N]	2	2	2	2	2	2	2	2	2	2	20
[C+S+M+N]	1	1	1	1	1	1	1	1	1	1	10
Total	19	20	20	20	20	20	21	22	24	24	210

Notes: The villages surveyed for this study included: Nkong-Neng (V1), Nsenlong (V2), Nkilzong (V3), Mbazoa (V4), Nkolzoa (V5), Bivouna (V6), Bidele (V7), Salakounou (V8), Efo (V9), Bikogo (V10). [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N]=Ndjansang.

Table A8

Number of respondents who grow selected fruit trees in the villages (V1 to V10) surveyed in the study area.

Main AF species*	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	Total
[C] with [S]	9	10	10	10	10	10	11	12	12	12	106
[C] with [M]	9	10	10	10	10	10	10	10	11	11	101
[C] with [N]	7	7	7	7	7	7	8	8	9	9	76

Notes: *with or without further fruit tree species. The villages surveyed for this study included: Nkong-Neng (V1), Nsenlong (V2), Nkilzong (V3), Mbazoa (V4), Nkolzoa (V5), Bivouna (V6), Bidele (V7), Salakounou (V8), Efo (V9), Bikogo (V10). [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang. Numbers do not add up to sample size due to double counting.

Table A9

Values (in FCFA/ha) of environmental benefits or services included in the computation of net social benefit (NSB) for different agroforestry systems.

Ecosystem services by scenarios	[C+S]	[C+M]	[C+N]	[C+S+M]	[C+S+N]	[C+M+N]	[C+S+M+N]
Baseline							
Climate regulation	16,483	27,815	6,696	24,209	18,028	30,905	26,784
Disturbance regulation	532	898	216	782	582	998	865
Water regulation	64	109	26	95	71	121	105
Water supply	218	367	88	320	238	408	354
Erosion control	2,718	4,586	1,104	3,991	2,972	5,095	4,416
Soil formation	113	190	46	166	123	212	183
Nutrient cycling	24	41	10	36	26	45	39
Waste treatment	968	1,633	393	1,421	1,058	1,814	1,572
Biological control	89	150	36	130	97	166	144
Food production	1,613	2,722	655	2,369	1,764	3,024	2,621
Raw materials	677	1,143	275	995	741	1,270	1,101
Genetic resources	12,233	20,643	4,970	17,967	13,380	22,937	19,879
Recreation	6,991	11,798	2,840	10,269	7,647	13,109	11,361
Cultural	16	27	7	24	18	30	26
Gas regulation	97	163	39	142	106	181	157
Pollinisation	242	408	98	355	265	453	393
Habitat/Refugia	314	531	128	462	344	590	511
Timber extraction	51,826	87,457	21,054	76,120	56,685	97,174	84,217
Bushmeat extraction	11,954	20,173	4,856	17,558	13,075	22,415	19,426
Employment and tax income	3,421	5,773	1,390	5,025	3,742	6,415	5,560
TOTAL	110,593	186,626	44,929	162,434	120,962	207,363	179,714
Cocoa sustainability certification (Sc. 1)							
Climate regulation	16,998	28,330	7,211	25,239	19,573	31,935	27,815
Disturbance regulation	549	915	233	815	632	1031	898
Water regulation	66	111	28	99	77	125	109
Water supply	225	374	95	333	259	422	367
Erosion control	2,802	4,671	1,189	4,161	3,227	5,265	4,586
Soil formation	116	194	49	173	134	219	190
Nutrient cycling	25	42	11	37	29	47	41
Waste treatment	998	1,663	423	1,482	1,149	1,875	1,633
Biological control	91	152	39	136	105	172	150
Food production	1,663	2,722	706	2,470	1,915	3,125	2,722
Raw materials	699	1,164	296	1,037	804	1,312	1,143
Genetic resources	12,615	21,026	5,352	18,732	14,527	23,701	20,643
Recreation	7,210	12,017	3,059	10,706	8,302	13,546	11,798
Cultural	17	28	7	25	19	31	27
Gas regulation	100	166	42	148	115	187	163
Pollinisation	249	416	106	370	287	469	408
Habitat/Refugia	324	540	138	482	373	609	531
Timber extraction	53,446	89,076	22,674	79,359	61,543	100,413	87,457
Bushmeat extraction	12,328	20,547	5,230	18,305	14,196	23,162	20,173

(continued on next page)

Table A9 (continued)

Ecosystem services by scenarios	[C+S]	[C+M]	[C+N]	[C+S+M]	[C+S+N]	[C+M+N]	[C+S+M+N]
Employment and tax income	3,528	5,880	1,497	5,239	4,063	6,629	5,773
TOTAL	114,050	190,083	48,385	169,346	131,330	214,275	186,626
Payment for voluntary carbon projects (Sc. 2)							
Climate regulation	16,998	28,330	7,211	24,724	19,058	31,420	27,300
Disturbance regulation	549	915	233	798	615	1014	881
Water regulation	66	111	28	97	75	123	107
Water supply	225	374	95	327	252	415	361
Erosion control	2,802	4,671	1,189	4,076	3,142	5,180	4,501
Soil formation	116	194	49	169	130	215	187
Nutrient cycling	25	42	11	36	28	46	40
Waste treatment	998	1,663	423	1,451	1,119	1,845	1,603
Biological control	91	152	39	133	103	169	147
Food production	1,663	2,772	706	2,419	1,865	3,074	2,671
Raw materials	699	1,164	296	1016	783	1,291	1,122
Genetic resources	12,615	21,026	5,352	18,350	14,144	23,319	20,261
Recreation	7,210	12,017	3,059	10,487	8,084	13,327	11,580
Cultural	17	28	7	24	19	31	27
Gas regulation	100	166	42	145	112	184	160
Pollinisation	249	416	106	363	280	461	401
Habitat/Refugia	324	540	138	472	364	599	521
Timber extraction	53,446	89,076	22,674	77,739	59,924	98,794	85,837
Bushmeat extraction	12,328	20,547	5,230	17,932	12,822	22,788	19,800
Employment and tax income	3,528	5,880	1,497	5,132	3,956	6,522	5,667
TOTAL	114,050	190,083	48,385	165,890	127,874	210,819	183,170
Tenure reform: Compensating the cocoa croppers' foregone revenue (Sc. 3a)							
Climate regulation	17,513	28,330	7,211	26,784	22,149	32,965	29,875
Disturbance regulation	565	915	233	865	715	1,064	965
Water regulation	68	111	28	105	87	129	117
Water supply	231	374	95	354	293	435	395
Erosion control	2,887	4,671	1,189	4,416	3,652	5,435	4,926
Soil formation	120	194	49	183	152	226	205
Nutrient cycling	26	42	11	39	32	48	44
Waste treatment	1,028	1,663	423	1,572	1,300	1,935	1,754
Biological control	94	152	39	144	119	177	161
Food production	1,714	2,772	706	2,621	2,167	3,226	2,923
Raw materials	720	1,164	296	1,101	910	1,355	1,228
Genetic resources	12,998	21,026	5,352	19,879	16,438	24,466	22,172
Recreation	7,428	12,017	3,059	11,361	9,395	13,983	12,672
Cultural	17	28	7	26	22	32	29
Gas regulation	103	166	42	157	130	193	175
Pollinisation	257	416	106	393	325	484	438
Habitat/Refugia	334	540	138	511	423	629	570
Timber extraction	55,065	89,076	22,674	84,217	69,641	103,652	93,935
Bushmeat extraction	12,702	20,547	5,230	19,426	16,064	23,909	21,667
Employment and tax income	3,635	5,880	1,497	5,560	4,597	6,843	6,201
TOTAL	117,506	190,083	48,385	179,714	148,610	221,187	200,451
Tenure reform: Equally sharing revenue between cocoa croppers and fruit producers (Sc. 3b)							
Climate regulation	22,149	31,420	7,211	28,845	25,754	36,571	33,481
Disturbance regulation	715	1,014	233	931	832	1,181	1,081
Water regulation	87	123	28	113	101	143	131
Water supply	293	415	95	381	340	483	442
Erosion control	3,652	5,180	1,189	4,756	4,246	6,030	5,520
Soil formation	152	215	49	197	176	250	229
Nutrient cycling	32	46	11	42	38	54	49
Waste treatment	1,300	1,845	423	1,693	1,512	2,147	1,965
Biological control	119	169	39	155	139	197	180
Food production	2,167	3,074	706	2,822	2,520	3,578	3,276
Raw materials	910	1,291	296	1,185	1,058	1,503	1,376
Genetic resources	16,438	23,319	5,352	21,408	19,114	27,142	24,848
Recreation	9,395	13,327	3,059	12,235	10,924	15,512	14,201
Cultural	22	31	7	28	25	36	33
Gas regulation	130	184	42	169	151	215	196
Pollinisation	325	461	106	423	378	537	491
Habitat/Refugia	423	599	138	550	491	698	639
Timber extraction	69,641	98,794	22,674	90,696	80,978	114,989	105,272
Bushmeat extraction	16,064	22,788	5,230	20,920	18,679	26,524	24,282
Employment and tax income	4,597	6,522	1,497	5,987	5,346	7,591	6,950
TOTAL	148,610	210,819	48,385	193,539	172,802	245,379	224,643

Notes: Computed from previous studies according to values by Costanza et al. (1997), Arowolo et al. (2018) and Tolessa et al. (2018) based on assumed density of 479 trees/ha. Hence, values in this study have been adjusted proportionally to the optimal fruit tree density of each agroforestry system from Table 5. [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang; 1 Euro = 656 FCFA; 1USD = 580 FCFA.

Source: Costanza et al. (1997); Arowolo et al. (2018); Tolessa et al. (2018); Jaza et al. (2019).

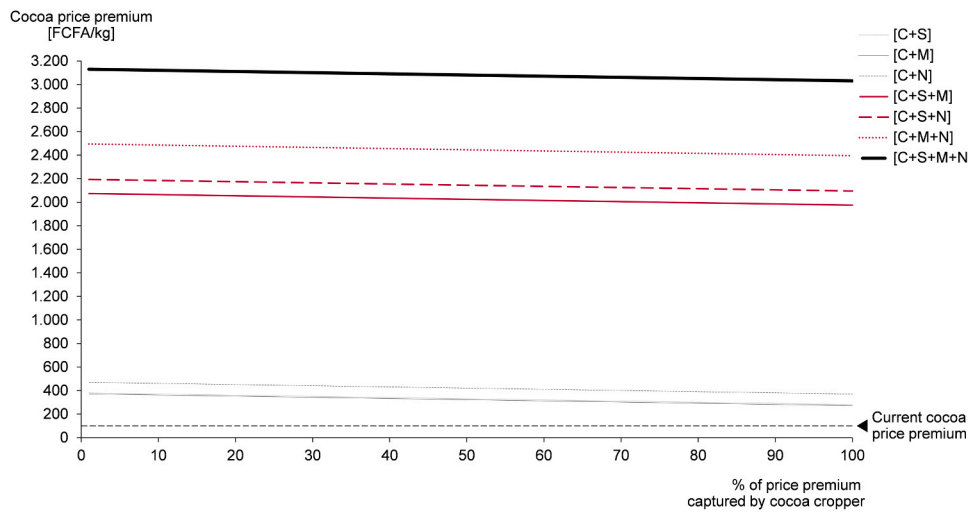


Fig. A1. Cocoa price premium required to induce the conversion of cocoa full-sun systems into agroforestry under Sc.1. Notes: Computed based on cocoa mono-cropping revenue of 409,000 FCFA/ha. This scenario excludes any further benefits from fruit tree growing other than the cocoa sustainability premium. X-axis depicts the continuum of sharing agreements between cocoa croppers and fruit tree growers (0% = price premium entirely captured by fruit tree grower to 100% = price premium entirely captured by cocoa cropper). For example, at X = 50% (price premium equally shared between both parties), a price premium of 2,025 FCFA/kg is required to make agroforestry acceptable to the cocoa cropper in the [C+S+M] system. [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang.

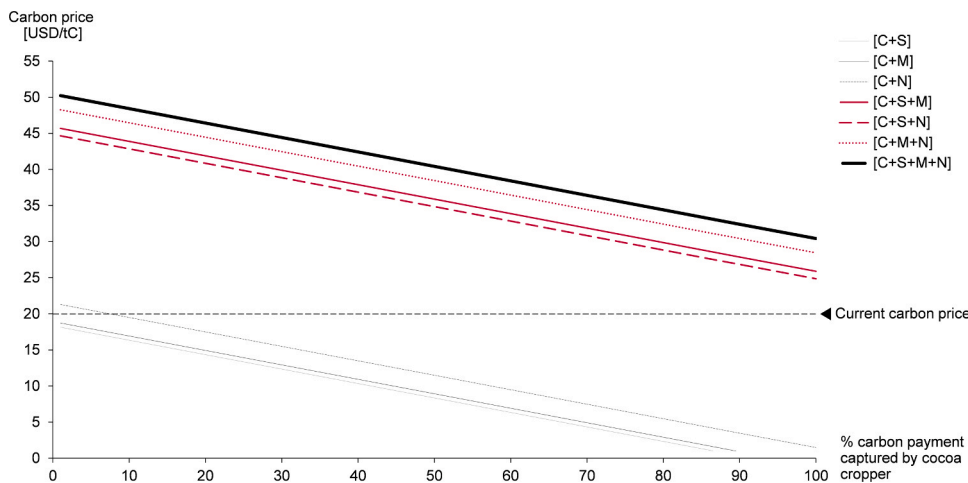


Fig. A2. Carbon price required to induce the conversion of cocoa full-sun systems into agroforestry under Sc.2. Notes: Computed based on cocoa mono-cropping revenue of 409,000 FCFA/ha, and carbon sequestration rates provided in Table A1. This scenario excludes any further benefits from fruit tree growing other than carbon payments. X-axis depicts the continuum of sharing agreements between cocoa croppers and fruit tree growers (0% = carbon payment entirely captured by fruit tree grower to 100% = carbon payment entirely captured by cocoa cropper). For example, at X = 50% (equal benefit sharing between both parties), a carbon price of 35.89 USD/t would be required to make agroforestry acceptable to the cocoa cropper in the [C+S+M] system. [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang.

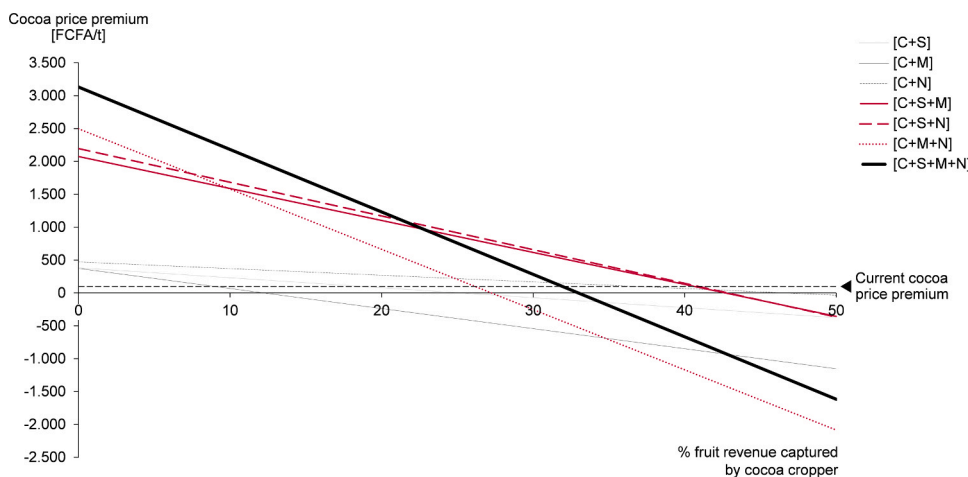


Fig. A3. Cocoa price premium required to induce the conversion of cocoa full-sun systems into agroforestry under Sc.3. Notes: Computed based on cocoa mono-cropping revenue of 409,000 FCFA/ha. This scenario excludes any further benefits from fruit tree growing other than fruit revenues. X-axis depicts the continuum of sharing agreements between cocoa croppers and fruit tree growers (0% = fruit revenue entirely captured by fruit tree grower to 100% = fruit revenue entirely captured by cocoa cropper). For example, at X = 20% (20% of fruit revenue allocated to cocoa cropper), a price premium of 1,103 FCFA/kg is required to make agroforestry acceptable to the cocoa cropper in the [C+S+M] system. [C] = Cocoa; [S] = Safout; [M] = Bush mango; [N] = Ndjansang.

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