LEAVES | Leveraging Agricultural Value Chains to Enhance Tropical Tree Cover and Slow Deforestation

BACKGROUND PAPER

PROFOR
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Coffee and Cocoa Agroforestry Systems: Pathways to Deforestation, Reforestation, and Tree Cover Change

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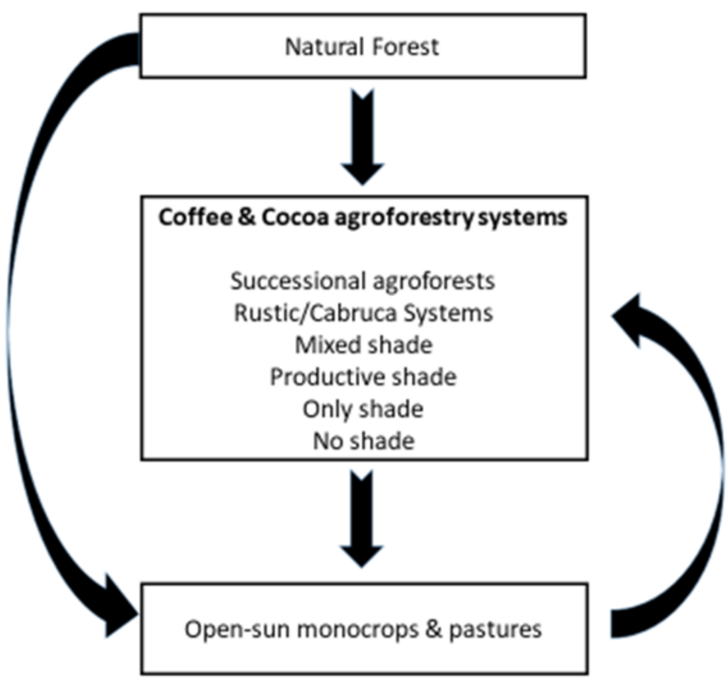
Executive Summary

Coffee cultivation covers 11 million hectares and involves 10 million farmers producing 22 million tons of green coffee annually. Coffee production influences the livelihoods of some 125 million people. Cocoa cultivation covers 10.2 million hectares and involves 10 million cocoa farmers producing 4.47 million tons annually. Cocoa production influences the livelihoods of some 40-50 million people. Globally, 48% of coffee and 31% of cocoa is cultivated under shade in agroforest systems. Coffee and cocoa are cultivated mainly by smallholder farmers.

Coffee and cocoa are drivers of both deforestation and reforestation. In the last two centuries, coffee production was responsible for dramatically transforming the landscape of the highlands in the New World by displacing sugarcane, cattle, and other minor crops as well as by displacing natural forests. In the last five decades, the expansion of cocoa cultivation led to the disappearance of 14–15 million hectares (ha) of tropical forests globally. Coffee and cocoa plantations may be established following four different pathways. (Figure 1) Transition pathways are not linear either in time or in space.

Figure 1: Pathway for the Establishment and Management of Coffee and Cocoa Agroforestry Systems



Coffee and cocoa plantations differ widely in terms of the use of trees in the shade canopy and in crop husbandry practices. At least six broad shade canopies typologies have been identified describing a gradient of increasing crop husbandry intensification, crop yields, and reductions in tree canopy cover. These typologies include (a) forest-like systems resulting from the introduction of coffee and cocoa in the natural forest ecosystem (successional agroforests, rustic systems, and *Cabrucas*), (b) mixed shade systems (various shade tree species, different plant habits and sizes), (c) productive shade systems (timber or fruit tree species), (d) specialized shade systems, (e) open sun, and (f) no-shade systems.

To minimize the deforestation footprint of coffee and cocoa cultivation and increase their role as agents of reforestation, five central question must be answered:

1. How to Avoid Clearing the Forest to Establish Coffee or Cocoa Plantations?
2. How to Counter the Growing Appetite for Full-Sun Coffee and Cocoa?
3. How to avoid losing shade tree cover?
4. How to Avoid Declining Coffee and Cocoa Areas to the Benefit of Other Crops?
5. How to Promote Replacing Other Crops by Coffee and Cocoa Agroforestry Systems?

The most relevant measures to reduce the **deforestation** and to increase **reforestation** include:

To reduce Deforestation:

1. Governments should improve the legal, institutional, policy and financial frameworks to increase the value of forest in private land and to enforce protection measures on national forests and conservation areas, including investment in the use of modern technologies to monitor land use changes in real time.
2. Additional support to curb deforestation stems from all climate initiatives linked to the United Nations' Framework Convention on Climate Change, UNFCCC, attempting to reduce emissions from deforestation and forest degradation, REDD+.
3. Support coffee and cocoa companies committed to zero deforestation, transparent, certified supply chains in combination with other important elements of commodity production such as no clearing on carbon-rich peat lands, no clearing on High Conservation Value areas, no clearance on High Carbon Stock (HCS) areas, and transparency in their production practices. Recently, the cocoa industry launched the Cocoa and Forest Initiative, signed by 22 major cocoa companies and the governments of Cote d'Ivoire and Ghana, the two largest world cocoa producers, but can be applied to other countries and geographies. Tools like the Global Forest Watch Commodities and MapsHub (www.maphubs.com) help companies have a closer look at where they source their cocoa beans from, thus making their supply chains traceable and transparent.

To increase Reforestation

Increasing the **profitability and financial resilience** of coffee and cocoa farming is essential to avoid clearing shaded coffee and cocoa to plant herbaceous crops and pastures, and to promote planting shaded coffee and cocoa to replace degraded herbaceous crops and pastures. Crop husbandry intensification in the quest for profitability usually involves the loss of shade tree cover. A range of measures are available to attain these goals, including.

1. Application of good agricultural and post-harvest practices such as the renovation and rehabilitation of unproductive plantations, use of superior genetic material and other inputs - including agrochemicals (especially fertilizers), agroforestry, integrated pest management, etc.
2. Value chain interventions such as certification for sustainability, improving commercial links between producers, exporters and manufacturers, appropriate financing mechanisms, and supporting the development of value chains for the on-farm production of timber and fruits.

3. Optimize the trades-off between ‘‘crop husbandry intensification’’ and the ‘‘reduction in shade level (shade canopy tree cover) and species richness”. Conceptual models and tools for the optimization of multi-objective coffee and cocoa shade canopies have not yet been developed and mainstreamed in the portfolio of good agricultural practices promoted for these two crops. The use of coffee and cocoa varieties and clones adapted to low light levels should be mainstreamed in farming with these crops.
4. Improve the legal, institutional, policy and financial frameworks to make trees in the shade canopy “visible” to farmers, extension services, policy makers, development planners and financial institutions. Secure tree tenure rights to farmers and certification of timber trees on farms are needed to facilitate the harvest, transport and use timber trees by farmers. One good example is the certification of timber tree planting in coffee farms in Honduras.
5. Promote, among farmers, the vision of “timber trees as crops” that need proper management to fully realize their contributions to both livelihoods and the environment.

The drivers, recommendations and knowledge gaps identified in this report are common to most (if not all) coffee and cocoa producing countries in Asia, Africa and Latin America with some adjustments. For instance, the legal context on forests and tree tenure, as well as the role of Governments vary drastically between growing regions and countries. A more in-depth analysis of the specific conditions (e.g. legal frameworks and tree tenure rights) in every geography leading to deforestation, cultivation of coffee and cacao, and the use of trees (especially timber, native and exotic species) in the shade canopy is warranted. Concerted actions between governments (national, jurisdictional), industry, traders and other value chain actors, farmers, financial institutions, and donors are essential to address the many facets of this central question: how to simultaneously minimize the deforestation footprint of coffee and cocoa cultivation while increasing their role as agents of reforestation?

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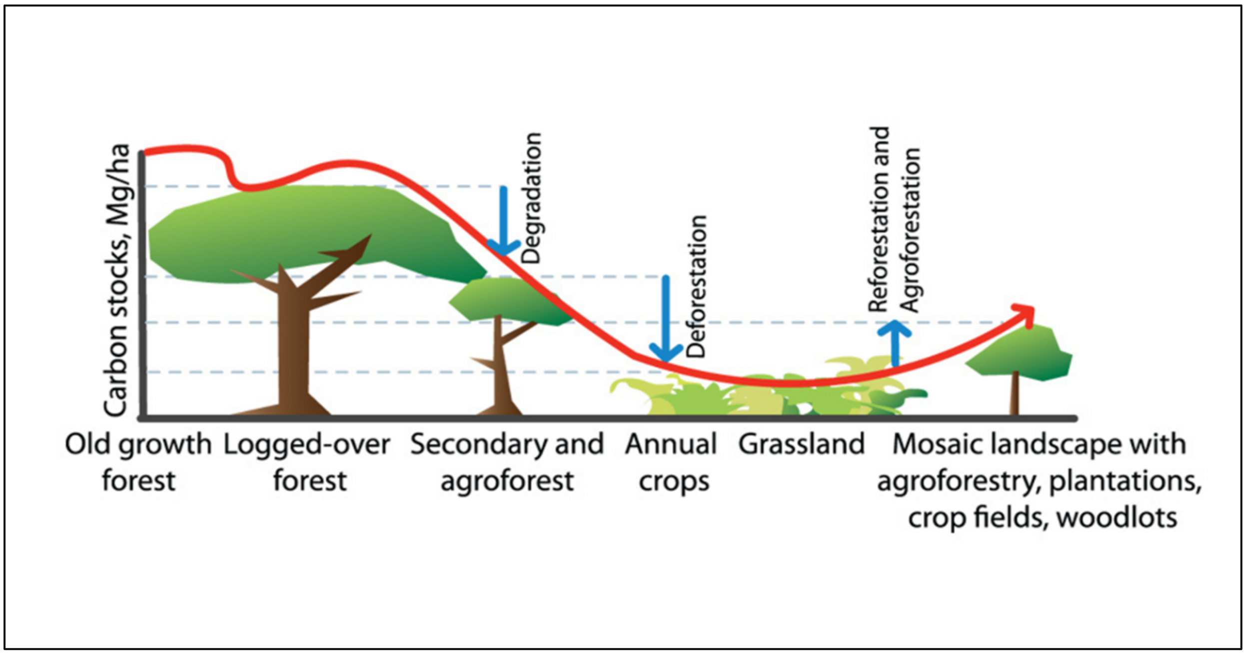
Introduction

Although the net loss rate of global forests was halved between 2010 and 2015, from 9.5 M ha/year- in the 1990s to 5.5 M ha/year in 2010 to 2015, forests are still being used, degraded, and eliminated at an unsustainable rate, especially in tropical and sub-tropical, low income countries (Keenan et al. 2015; Sloan and Sayer 2015). Commercial agriculture (68%) followed by subsistence/smallholder agriculture (33%) are the top drivers of deforestation (FAO 2016; Hosonuma et al. 2012; Kalamandeen et al. 2018).

The transformation of the forests into other agricultural land uses is usually represented by a "forest transition curve" also referred to as the "tree cover transition curve." The curve depicts how forests and tree cover decrease along a gradient of land use change and agricultural intensification until a point is reached when tree cover is brought back into the agricultural land using various agroforestry or reforestation schemes (Figure 2).

Figure 2. Forest Transition Curve



Source: Barbier et al. 2010, Dewi et al. 2017

As forests are converted into agricultural land and pastures, some trees are retained to provide goods and services essential for rural livelihoods as well as other ecosystem services. Trees outside the forest (TOF) are now receiving more attention by researchers, development planners, farmers, and policy makers (de Foresta et al. 2013). Zomer et al. (2014) estimated that 48% of the available agricultural lands have at least 10% of tree cover, and FAO's most recent Forest Resources Assessment Report estimated the area under trees on farms at 2.8 million hectares worldwide; other wooded lands represented an additional 1.2 million hectares (FAO 2016)[1]. Tropical countries accounted for 43% of total, wooded, non-forest area (Keenan et al. 2015). Agroforestry systems (one type of TOF) and tree cover on agricultural land are not systematically accounted for in either global carbon budgets or national carbon accounting (Zomer et al. 2016).

[1]Other wooded land, describes land of at least 0.5 ha that is covered by trees higher than 5m, and either the tree canopy cover is 5–10%, or the total cover of trees, shrubs and bushes exceeds 10%.

Coffee is cultivated on 11 million hectares and involves 25 million farmers producing 22 million tons of green coffee annually (FAO 2016; Waller et al. 2007; Bacon 2005; Jha et al. 2014). Around 125 million people depend on coffee for their livelihoods[2]. Cocoa is cultivated in 10.2 million hectares and involves 10 million cocoa farmers producing 4.47 million tons of dry cocoa beans annually (Vaast & Somarriba 2014; FAO 2016). Between 40 and 50 million people depend on cocoa for their livelihoods (Kroeger et al. 2017a, b). In Latin America, coffee and cocoa cover 5.61 and 1.63 million ha respectively (Somarriba et al. 2012). Coffee cultivation area remains stable, but cocoa is expanding (Wessel & Quist-Wessel 2015). Coffee and cocoa are cultivated mainly by smallholder farmers.

Coffee and cocoa are typically grown under shade, in agroforestry systems (Table 1). Using data in Table 1, it is estimated that shaded cocoa cover 31% of total global cultivated area, with notable differences between both countries and continents (**Error! Reference source not found.**). In Latin America, shaded cocoa represents 85% of total cultivated area (Somarriba et al 2012). Forty eight percent of the coffee is cultivated under shade, with notorious differences between countries (Table 1). The use of shade, especially the use of species-rich, structurally complex shade canopies is decreasing worldwide (Jha et al. 2014).

Table 1: Area Planted for Coffee and Cocoa, Total and Percent under Tree Shade in Selected Countries

Country	Coffee			Cocoa		
	Area (ha)	Shade (%)	Sun (%)	Area (ha)	Shade (%)	Sun (%)
Brazil	1,994,761	5	95	720,053	93	7
Côte d´Ivoire	1,058,084	*na*	*na*	2,851,084	26	74%
Indonesia	1,228,512	60	40	1,701,351	*na*	90+
Ecuador	79,744	24	76	537,410	20	80
Colombia	865, 889	39	61	173,016	75	25
Vietnam	597,597	25	75	*na*	*na*	*na*
Ghana	*na*	*na*	*na*	1,683,765	25	75
Peru	425,416	98	2	125,580	90+	*
Costa Rica	84,133	82	18	4,000	100	-
Mexico	727,385	89	11	58,734	90+	*
Haiti	79,857	100	0	26,975	100	0
Honduras	382,662	80	20	1,889	90+	*
Guatemala	274,177	98	2	4,333	90+	*
Dominican Republic	78,747	100	0	152,261	100	*
Nicaragua	120,050	47	53	9,310	90+	*
El Salvador	140,000	99	1	941	85	15
Venezuela	130,795	*na*	*na*	64,462	90+	*

[2] https://www.fairtrade.org.uk/en/farmers-and-workers/coffee

Source: Jha et al. 2011, INEC 2015, DANE 2017, FAOSTAT 2017, Castillo 2016, FEDECACAO 2018[3], agrodominicano.blogspot.com, Somarriba et al. 2012
**areas in full sun insignificant, na: data not available*

Six broad shade canopy typologies have been described for both coffee and cocoa (see descriptions in Annex 1). These include (a) no-shade, monocrop shade canopies, (b) shade-only, service species such as Inga, Erytrhina, Gliricidia, Albizia shade canopies with low structural complexity, (c) coffee/cocoa shade canopies with one or a few productive shade species (e.g. cocoa-bananas, coffee-timber, rubber, or fruit tree species) and low structural complexity, (d) mixed shade canopy systems including planted service or productive tree species plus other tree species retained either from the original native forest or recruited from natural regeneration, (e) rustic shade canopy systems (known as Cabrucas in the case of cocoa) where 100% of the lower canopy and at least 60 % of the upper canopy trees of the original forest are removed and then coffee/cocoa planted underneath (Moguel and Toledo 1999), and (f) successional coffee/cocoa shade canopy agroforests where the cultivation of crops involves a period dominated by the natural forest succession at the site (Somarriba and Lachenaud 2013). A gradient of increasing tree cover and standing carbon have been documented for these typologies (Ehrenbergerová et al. 2016; Pinoargote et al. 2017; Somarriba et al. 2013). Cocoa and coffee yields decrease along this gradient of increasing standing carbon. Very little information is available on successional agroforests.

[3] Available http://www.fedecacao.com.co/portal/index.php/es/2015-02-12-17-20-59/nacionales

Photo 1: Cocoa-timber (Terminalia ivorensis) in Honduras

Source: Jesus Sanchez, FHIA

Transition Pathways

Coffee and cocoa are drivers of both deforestation and reforestation. Coffee and cocoa plantations may be established following four different pathways (Figure 2) For instance, pristine forests may be totally removed, and the land planted for various forms of open-sun agriculture lands or pastures. These may eventually be transformed into coffee or cocoa plantations. Forests may be directly transformed into different typologies of cocoa or coffee plantations. Finally, coffee or cocoa plantations may be converted to open-sun agriculture land or pastures. Transition pathways are not linear in time or space.

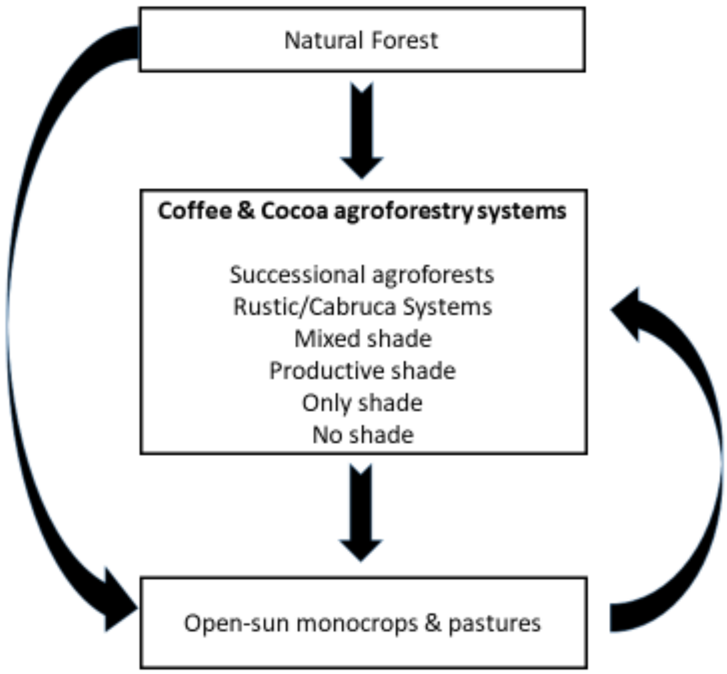


Figure 2. Transition pathways between natural forests, coffee/cocoa agroforestry systems, and other land uses.

Five central questions must be addressed to assess the deforestation/reforestation pathways:

1. How to avoid clearing the forests to establish coffee/cocoa plantations;

2. How to counter the growing appetite for full-sun coffee and cocoa;

3. How to avoid losing shade tree cover?

3. How to avoid declining coffee or cocoa areas to the benefit of other crops; and

4. How to promote replacing other crops by coffee or cocoa agroforestry systems.

In what follows we enumerate the recommendations corresponding to each question.

How to Avoid Clearing the Forest to Establish Coffee or Cocoa Plantations

Coffee and cocoa have been important drivers of deforestation in the last two centuries. The French were the first to introduce coffee beans to the New World around 1700s, and by the second half of the 1800s coffee production had emerged as an important cash crop, displacing sugarcane, cattle, and other minor crops including also natural forests. (Rice 1999; Pasos et al. 1994). In the 21st century in Honduras, coffee production increased dramatically from 2.5 million to 5.9 million 60 kg bags per year, at the expense of natural highland forests (Palencia 2012; Ruben et al. 2018). Coffee cultivation is also expanding in the Amazonian regions of Ecuador and Peru.

Cocoa is characterized by shifts of production from one country to another, and from one region to another within countries. Cocoa production shifted from Mexico to Central America in the 16th century, to the Caribbean in the 17th, to Venezuela in the 18th, to Ecuador and then Sao Tomé in the 19th, to Brazil and Ghana and Nigeria in the early 20th century, and then to Côte d'Ivoire. In the 21st century, cocoa continues expanding into the natural forests of West and Central African countries, Indonesia, and

Peru's Amazon forests (Asner et al. 2014; Harris et al. 2015; Vaast and Somarriba 2014). The relationship between the expansion of cocoa into humid forest zones is well documented for Africa (Ruf and Zadi 1998).

The underlying causes behind the elimination of natural forests to plant coffee or cocoa are varied. A recent study in West Africa states "the trajectory of deforestation due to cocoa production has remained upward primarily because of rising demand for chocolate, decreasing production capacity from aging cocoa trees, lack of good agricultural practices and the shrinking suitable land area due to climate change. These factors create further incentive to convert forests to farmlands for cocoa, which threatens remaining forested and protected areas" (Kroeger et al 2017). Deforestation from 1986 to 2015 is described by Ruf and Varlet (2017). Cocoa yield has stagnated over the last five decades, but world cocoa production has doubled, mostly through extension on pioneer fronts in forest areas (Vaast and Somarriba 2014). This led to the disappearance of 14–15 million ha of tropical forests globally (Clough et al. 2009).

Fortunately, important counter measures have been put in place. The period between mid-1980 and mid-1990s was a time of deep structural changes in Latin America as governments transitioned from authoritarian regimes to democracy with major transformations at the institutional, political, economic, and social levels. In this period, a paradigm shift occurred and two new ideologies emerged: neoliberalism and environmentalism (Hecht 2014). New approaches emerged that had direct effects in slowing deforestation processes. These new approaches included the recognition of the role of new forms of governance (NGOs and forest-based social movement/organizations), new environmental policies (including property rights and occupation), decentralization, green markets, market expansion, United Nations Conventions such as the United Nations Framework Convention on Climate Change (UNFCCC), REDD+, and industry concerns and actions (Brown and Zarin 2013). Major cocoa companies have recently committed to zero-deforestation supply chains in combination with other important elements of commodity production such as no clearing on carbon-rich peat lands, no clearing on high conservation value (HCV) areas, no clearance on high carbon stock (HCS) areas, and transparency in their production practices. Companies have placed high hopes on certification in combination with a range of other measures to reduce deforestation.

A comprehensive analysis of the impact of this strategy has been recently published by the World Bank and others (Kroeger et al 2017a). They concluded that: "The deforestation-related requirements for the various certification schemes contain important nuances that determine the effectiveness and level of forest protection required by each standard. Companies' plans for addressing deforestation in cocoa are varied and include: training of farmers around avoiding deforestation, intensification and cocoa tree rehabilitation or replanting, promotion of agroforestry to increase forest trees-on-farms and push for the preservation of remaining forests. For these companies, a vision for zero-deforestation cocoa is summed up in several overarching principles and key strategies, including: the protection of all remaining natural primary and secondary forest, legality and transparency, integration and alignment of zero-deforestation goal into long-term public and private sector strategies (e.g. with REDD+, see https://innovation-forum.co.uk/analysis.php?s=think-big-to-tackle-deforestation), sustainability programs that operate at scale through jurisdictional or landscape approaches, public-private cooperation, sustainable financing to stimulate local producers to restore or replant their cocoa farms to increase productivity." A skeptical view of the achievements of these interventions is provided by Ruf and Varlet (2017).

The number of private commitments to reduce deforestation from supply chains has greatly increased in recent years, with at least 760 public commitments by 447 producers, processors, traders, manufacturers, and retailers as of March 2017 (Lambin et al. 2018). Instruments to operationalize these commitments are varied, but include round tables for sustainable production, moratoria or legislation to restrict market access to commodities sourced from areas being deforested, etc. For instance, significant reduction in deforestation rates in the Brazilian Amazon in the last decade has been reported and credited to environmental legislation introduced to regulate value chains of agricultural commodities linked to deforestation (Assuncao et al. 2012, Nepstad et al. 2014; Kalamandeen et al. 2018). A rich and detailed guide to reduce tropical deforestation is provided by Daniel Nepstad in a recent commentary.[4]

Recently, the cocoa industry launched the Cocoa and Forest Initiative to tackle the triple challenge of increasing productivity on limited land, reducing pressure on forests and ecosystems, and enhancing climate change resilience (Kroeger et al. 2017b). The initiative has been signed by 22 major cocoa companies and the governments of Cote d'Ivoire and Ghana, the two largest world cocoa producers. However, the initiative can be applied to other countries and geographies. The goal is to develop a climate-smart cocoa (CSC) economy that encapsulates three goals: increased productivity of agricultural lands, reduced greenhouse-gas emissions, and increased climate resilience. Renovation and rehabilitation of the aging and pest-infected tree stock in West Africa is an essential element of CSC. The strategy revolves around eight priorities that include:

1. Operationalizing cocoa sector action plans;
2. Agreeing on common operational principles and definitions;
3. Establishing multi-stakeholder engagement and action platforms;
4. Developing integrated smallholder support packages;
5. Developing a financing strategy;
6. Delivering finance and support to smallholders;
7. Monitoring impact and linking to a zero-deforestation agenda; and
8. Strengthening governance.

Tools like the Global Forest Watch Commodities and the HCS approach provide a practical and credible way to identify degraded areas suitable for plantation development and forest areas that merit protection to maintain and enhance carbon, biodiversity, and social values, thus helping cocoa companies to make supply chains traceable and transparent. MapsHub is yet another attempt to help companies have a closer look at where their cocoa beans come from and its relationship with nearby forests. Despite these advances, curbing the many opportunities farmers and collectors have in 'laundering' cocoa beans from deforestation areas is a still pending, paramount task.

How to Counter the Growing Appetite for Full-Sun Coffee and Cocoa

There is a growing consensus that cocoa supply in the future is highly insecure: "a mere 3% growth in consumption would require the addition of 1.8 million metric tons of cocoa by 2025, and the cocoa crop would need to increase by nearly 50% to meet projected demand" (Blommer 2011). Increasing on-farm yields is one of the biggest challenges. Recent international fora have emphasized the need to intensify cocoa cultivation through the use of improved genetic material and improved agricultural practices based on the use of agro-chemicals, especially inorganic fertilizers, and wide spread rehabilitation and renovation of old, diseased, un-productive farms (Blommer 2011; Jazeer et al. 2018; Rahn et al. 2018b; Vaast and Somarriba 2014; Kroeger et al. 2017a, b).

Historically, intensification to achieve higher crop yields in both coffee and cocoa has brought about a reduction in both shade levels and species richness (Perfecto et al. 2005; Ruf 2011; Wade et al. 2010; Tondoh et al. 2015). Numerous studies document these changes. For instance, in Indonesia, the transformation of primary forests into cocoa agroforestry systems decreased forest carbon by 75%–88% (Smiley and Kroschel 2008; Stephan-Dewenter et al. 2007), in Central and West Africa by 50% (Duguma

[4] Earth Innovation Institute info@earthinnovation.org, at: https://news.mongabay.com/2018/03/tropical-deforestation-the-need-for-a-strategy-adjustment-commentary/

et al. 2001), 38 % in Cameroon (Kotto-Same et al. 1997), 60%-75% in other West African countries (Gockowski and Sonwa 2011), 15%-75% in Ghana (Wade et al. 2010), 82% in the *Mata Atlantica* of Brazil (Gama-Rodrigues et al. 2011), and 72% in Central America (Somarriba et al. 2013). Similar results have been documented for the transformation of natural forests into coffee plantations (van Noordwijk et al. 2002).

The magnitude of the reduction in forest biomass depends on the typology of the coffee/cocoa agroforestry system established. Ideally, coffee/cocoa agroforestry systems should retain as much biological diversity and biomass from the original forest while attaining high coffee/cocoa yields. This is a difficult tradeoff to control because shade levels are directly related to shade tree biomass, and crop yield is inversely proportional to shade levels. Coffee and cocoa varieties and clones adapted to low light levels should be identified, tested under various agroforestry designs, and delivered to farmers. Furthermore, there are limits to the number of tree species that can be effectively managed in a shade canopy. Fewer shade tree species in the shade canopy are easier to manage. Imagine the complexity of selecting pruning frequency and intensity for 30+ tree species in a shade canopy, each with different crown architecture, canopy growth rate, tolerance to pollarding and so on! There is clearly a need to optimize the trades-off between the ‘‘use of new cocoa genotypes combined with high external inputs to increase cocoa yield’’ and the ‘‘reduction in shade level and species richness’’ (Steffan-Dewenter et al. 2007).

Exactly how many shade trees should be in a coffee or cocoa plantation, and in what conditions, is still an open question. Even though most researchers and farmers concur with the fact that "too much shade" decreases coffee and cocoa yields, low to moderate shade may be more beneficial than no shade at all (Meylan et al 2017; Muschler 2001; Ruf 2011). An "ideal shade level" must be determined for each particular combination of climate, soil, pest/disease environment, and crop management practice (Avelino et al. 2006; Allinne et al. 2016; Deheuvels et al. 2012; Jazeer et al. 2018b; Obiri et al. 2007; Pinoargote et al. 2017). There are many recipes as each situation is different. Estimates of the ideal shade cover for Arabica coffee in the Americas vary between 15% and 65% canopy cover (Beer et al. 1998; Soto-Pinto et al. 2010); Staver et al. 2001; Campanha et al. 2005). The relationship between shade and pests/diseases is very complex because certain shade conditions that may be favorable for some pests/diseases, may be detrimental to others (Allinne et al. 2016). A significant information gap still remains in order to fully understand the effect of shade trees in coffee agroforestry system across a wide variety of management approaches, environments, and climates (van Oijen et al. 2010).

Recent studies warn against focusing exclusively on coffee/cocoa yields when evaluating the impacts of shade on the financial performance of a coffee or cocoa plantation. A more comprehensive economic evaluation should consider differential cost structures and additional income from fruit, firewood, and timber in coffee and cocoa agroforestry systems. Various studies show that when these other factors are considered, the total financial output of shaded systems equals or even surpasses the financial output of open-sun, intensively managed monocultures (Pinoargote et al. 2017; Jezeer et al. 2018; Cerda et al. 2014; Rice 2008). The advantage of shaded systems may be even larger when ecosystem services, premium prices for certified products, and reduction in financial vulnerability (increased resilience of the household) as a result of product diversification are factored in (Bacon 2005; Beuschelt and Zeller 2011; Bravo-Monroy et al. 2016; de Beenhouwer et al. 2013; Gobi 2000; Gordon et al. 2007; Haggar et al. 2017; Lyndbaek et al. 2001; Ruf and Schroth 2015; de Souza et al. 2015). Profitability and resilience of the coffee and cocoa agroforestry systems (and not only crop yields) are the proper criteria for assessing the performance of these systems.

How to avoid losing shade tree cover

Many factors militate against the retention of shade trees in the plantation. Some are presented below.

- Crop husbandry intensification to achieve higher coffee/cocoa yields often requires reducing shade levels (Jagoret et al. 2017; Rhan et al. 2018b; Jezeer et al. 2018; Tondoh et al. 2015). Outcomes of this intensification process in coffee and cocoa vary among countries. In Brazil and Colombia, 95% and 70% of the respective coffee areas, are now grown in an open-sun environment (Jha et al. 2011), while in El Salvador, Mexico, and Peru, shade-grown systems persist. In the case of cocoa, aggressive modernization programs are underway in countries such as Ecuador, Peru, Brazil, and Colombia. Extension services in many coffee countries including Colombia and Costa Rica and cocoa counties such as Indonesia and Cote d'Ivoire have been the first to recommend farmers to remove the shade and later on to re-introduce it. No scientific publications could be located addressing this important issue. The many cycles of intensification of coffee and cocoa have resulted in a dramatic change in the ways these crops are cultivated (Jha et al. 2011; O'Connell 2013; Rice 1999; Staver et al. 2013).

- Trees on farms are "invisible" to extension agents and policy makers and are not properly represented in forest laws and institutions (Somarriba et al. 2017). Consequently, trees are neither part of the extension portfolio offered to farmers to improve farm productivity, nor part of the policies and support programs offered by governments, NGOs and donors.

- Legislation is unsupportive and disincentive to plant and use farm trees. Over-regulation, especially timber trees, causes difficulties for farmers to obtain permits to harvest, transport, and use their trees leading them to illegality and lower returns from the sale of farm timber. Legislation to protect native tree species may have perverse effects. For instance, in the coffee producing areas of India, native shade tree species are protected and cannot be harvested. Consequently, farmers illegally kill native trees and replace them with the exotic *Grevillea robusta*.

- Underdeveloped value chains for fruit and timber result in significant on-farm losses that deprive farmers of much-needed additional income (Vaast et al. 2015).

- Trees may compete for soil water affecting the growth and yield of coffee/cocoa, especially in the current climate change scenario in Africa (Abdulai et al. 2018; Padovan et al. 2015; Rahn et al. 2018a).

- Shade trees create micro-environmental conditions that favor the incidence of pests and pathogens that reduce crop yields (Boudrot et al. 2016, López-Bravo et al. 2012). However, pests and pathogens respond differently to shade in coffee and cocoa, with some increasing with shade and other decreasing under shade (Armbrecht and Gallegos 2007; Bosselmann et al. 2009; Domfeh et al. 2011; Feliz-Matos et al. 2004; Lopez-Bravo et al. 2012; Mouen Bedimo et al. 2008; Philpott and Ambrecht 2006; Schroth et al. 2000; Staver et al. 2001).

The intensification may be a response to: a) increased demand for coffee and cocoa; b) the spread of diseases (Boudrot et al. 2016; López-Bravo et al. 2012; Pereira et al. 1989; Phillips-Mora et al. 2006; Rice 1999); c) the availability of new, high yielding, disease tolerant, high quality coffee/cocoa varieties (Jagoret et al. 2017); d) the need to increase crop productivity and financial performance (Ruf 2011; Gockowski and Sonwa 2011); and e) favorable economic conditions for coffee and cocoa prices in the international market.

It is commonly argued that crop intensification increases productivity per unit area, and "spare" land can be used for forestry plantations or recovery of natural forests. Others argue that it is better to "share" the land and simultaneously grow coffee/cacao and other crops such as shade trees on the same land even though crop yields are lower than in intensive systems. The land sparing vs. land sharing debate has not been settled and some authors have suggested that the best alternative is a mixed strategy combining both approaches at the landscape level (Schroth et al. 2011). Some evidence has been presented that supports the argument that intensification leads to increases in forest area on a regional scale. For instance, intensification of coffee production in Colombia has resulted in a more diverse and heterogeneous landscape as land becomes available to other crops/land-uses, including forest regrowth and the preservation of existing forest patches. Coffee dominated landscapes have more area under forests, larger forest patches, and better connectivity between patches than non-coffee areas (Guhl 2008; Rueda et al. 2014; Sánchez-Cuervo et al. 2012).

Several mechanisms have been effective in promoting tree planting/retention in coffee and cocoa agroforestry systems. Some are presented below.

- Alignment between agriculture, forestry, and environmental legislation and policies can be effective. A successful example, the Honduran government "Program of Agroforestry, Environment and Climate Change" (Decree 56-2007) promotes the planting of timber trees in coffee farms by giving the National Coffee Institute (IHCAFE) the capacity to certify tree planting to facilitate the harvest, transportation, and use of timber produced in coffee farms. As of 2017, over 1.5 million ha of timber trees have been planted (Jiménez-Nehring 2012). In West Africa, the certification of the timber trees planted by farmers in their cocoa plantations has been recommended as the best option to stimulate the retention and utilization of trees in a cocoa plantation (Ruf & Varlet 2017). In Colombia, the Colombian Federation of Coffee Growers (FEDECAFE) has developed a far-reaching forest program to promote better silvicultural practices, to increase tree cover in coffee farms, to protect forest patches, and to implement other good land management practices across 58 municipalities.[5] In Ethiopia, a partnership between the Government, the Nespresso Sustainable Innovation Fund, TechnoServe, and the International Finance Corporation have joined forces and funding to promote the planting of shade trees in 40,000 smallholder coffee farms in the Oromia region with links to, and additional funding from, REDD+ programs.[6]

- The simplification of protocols to obtain permits to harvest, transport, and use farm timber has had direct, positive effects on the willingness of Central American farmers to retain and plant timber trees in their farms (Scheelje 2009; Somarriba et al. 2012).

- Proper tree tenure rights for farmers to retain, cultivate, and use their trees is important (Place et al. 2012, Robinson et al. 2014; Ruf and Zadi 1998). For instance, in Guatemala, the national forest policy created a portfolio of economic incentives to stimulate tree planting under agroforestry systems such as shaded coffee and cocoa, forest plantation, and forest management. One of the programs focuses on smallholder farmers with less than 15 ha of land. This program, known as the PINPEP Law (Decree No.51-2010), has supported some 20 thousand reforestation projects covering 69,405 ha with a governmental support of USD$58 million.[7]

- The evolution of green markets, sustainability standards, labels, and certification of both coffee and cacao have proven useful.(Giovannucci and Ponte 2005; Millard 2011; Schroth et al. 2016). Even though some authors have discredited the beneficial effects of certification schemes to halt deforestation or to favor the retention of trees in cocoa farms, the amount of evidence on the positive effects of certification on the recovery of woody vegetation cannot be ignored (Ruf and Varlet 2017; Hardt et al. 2015; Fenger et al. 2016; Ibanez & Blackman 2016; Rueda et al. 2014; Tayleur et al. 2018). In Ethiopia, certified shaded coffee farms increased the likelihood of forests conservation (Takahashi and Todo 2014). In Colombian coffee-growing regions, the recovery of forests is noticeable (Sánchez-Cuervo et al. 2012). Analysis of the spatial distribution of certified

[5] www.federaciondecafeteros.org
[6] https://www.biocarbonfund-isfl.org/ethiopia-program
[7] http://inab.gob.gt

coffee farms in Central America showed that rates of tree cover loss were lower in most cells with certification (Tayleur et al. 2018).

- Coffee certification standards such as the Smithsonian Bird Friendly® and the Rainforest Alliance (RA) have specific requirements in terms of tree species richness, vertical stratification, crown cover, and phenology for farmers to comply with. For example, RA certification requires at least 40% shade cover in coffee agroforestry systems. The retention of trees in RA certification is promoted as a non-point source pollution control (de Jesús-Crespo et al. 2016). Palmieri (2008) found correlation between certification and higher rates of compliance with the Brazilian Forest Code among coffee farmers.

How to Avoid Declining Coffee and Cocoa Areas to the Benefit of Other Crops and Land Uses

Drivers leading farmers to replace coffee/cocoa by other land uses are numerous (Blackman et al. 2012). Equally numerous are the measures needed to address this issue. In general, we are looking for measures that make the cultivation of coffee/cocoa more attractive than other alternative land uses and crops. Various measures contribute to this goal.

a) Increasing on-farm profitability through higher international prices

There has been a long-term fall in international coffee/cocoa prices and hikes in both labor and input prices (Padron and Burger 2015; Somarriba et al. 2001; Vaast et al. 2015). The evolution of green markets, sustainability standards, labels, and certification increase the financial performance and reduce the financial vulnerability of both coffee and cacao (Méndez et al. 2010). This, in turn, encourage farmers to stay in business (Pinto et al. 2014). In Ecuador, two market strategies, geographic indication and denomination of origin, helped the country to promote a high cacao quality image and helped farmers to access better market niches (Bacon 2005; Beuchelt and Zeller 2011; Bravo-Monroy et al. 2016; de Beenhouwer et al. 2013; Gobbi 2000; Gordon et al. 2007; Haggar et al. 2017; Jeezer et al. 2017; Blare and Useche 2013; Vellema et al. 2015). In Honduras, the denomination of origin *Café Marcala* was created to recognize the high quality of the coffee and to provide access to specialty coffee market.[8] Similar experiences have been documented in Colombia, which converted other agricultural land uses into coffee in highland areas with high cup quality profile (Rueda et al. 2014).

b) Increasing crop yield

- ***Integrated pest/disease management (IPM).*** There are four pests and disease that are responsible for the massive abandonment and replacement of coffee and cocoa plantations. Moniliasis (*Moniliophtora roreri*) has spread in Latin America in the last 40 years (Phillips-Mora et al. 2006). Witch's broom (*Crinipellis perniciosa*) has caused damage in Southeastern Brazil (Pereira et al. 1989). Coffee leaf rust (*Hemileia vastatrix*) has been a plague in Central and South America (Avelino et al. 2015; Boudrot et al. 2016, López-Bravo et al. 2012). Finally, cocoa swollen shoot virus has damaged crops in Ghana (Domfeh et al. 2011; Morton 2007). Crop yield losses to these pests and diseases can be substantial. The application of sound and cost-effective IPM protocols is a prerequisite for achieving high coffee and cocoa yields.
- ***Fertilization to avoid degradation of soil fertility (in cocoa mostly)*** Smallholder cocoa cultivation, accounting for 80% of cultivation area, rarely use chemical fertilizers to restore soil fertility.[9] Cocoa plots degrade after 50-70 years of continuous cultivation, making it very difficult to replant cacao in the same plot (Anim-Kwapong and Osei-Bonsu 2009; Ojeniyi 1986). Loss of soil fertility is one of the main proximate causes for

[8] http://cafemarcala.blogspot.com/2012/05/procesos-calidad-origen-cafe-honduras.html
[9] www.worldcocoafoundation.org

shifting cocoa cultivation from one region to another in the well-described boom and bust cycles of cocoa growing worldwide (Ruf and Zadi 1998).

c) ***Intercropping and shade tree products for household consumption and sale***

Coupled with improved value chains to channel fruit and timber production to markets, the inclusion of revenues from intercropping and tree products for household consumption and sale help farmers to obtain early revenues, reduce plantation establishment costs, avoid losses and achieve acceptable returns (Jezeer et al. 2017, 2018; Pinoargote et al. 2017; Cerda et al. 2014; Mehta and Leuschner 1997; de Souza et al. 2015; Vaast et al 2015). Diversification with timber and fruit contributes to the long-term financial stability and lower vulnerability of the household (Ruf and Schroth 2015; Godoy and Bennett 1989).

d) Payments for ecosystem services

Payments for the ecosystem services provided by coffee and cocoa agroforestry systems and the adoption of certification schemes has helped farmers to secure higher and less volatile coffee and cocoa prices (Bacon 2005; Beuchelt and Zellerr 2011; Gobbi 2000; Waldron et al. 2015).

a) Partnerships and multi-stakeholder platforms for sustainability

Inter-sectorial networks of partnerships or multi-stakeholder platforms have emerged in the coffee and cocoa sector to demonstrate progress towards sustainable yields (Blommer 2011; Levy et al. 2016; Millard 2011; Bitzer et al. 2012ab). Several outstanding examples include:

- The Swiss Platform for Sustainable Cocoa, a multi stakeholder initiative, was launched in 2015 to promote sustainability in the cocoa business.[10] Chocosuisse, the State Secretariat for Economic Affairs (SECO), and non-governmental organizations such as Swisscontact and Helvetas back the initiative.

- Similar multi-stakeholder partnerships involving farmer associations, governments, chocolate manufacturers, exporter, donors, and micro-credit organizations have been implemented in Indonesia by Blummer Chocolate Company. This partnership reached 20000+ farmers and focused on "the commercial link" between producers, manufacturers, and end users (Blummer 2011).

- Kraft Foods pledged that all of its coffee brands in Europe will use fully certified sustainable sourcing by 2015.[11]

- In partnership with Conservation International, Starbucks sources from coffee farmers certified to its own standards, the Coffee and Farmer Equity (C.A.F.E.) Practices. This partnership has invested more than USD$150 million to support coffee communities through its Global Farmer Fund.[12] In 2008, Starbucks launched COCOA Practices, a program aimed at using 100% ethically sourced cocoa by 2020 in all Starbucks cocoa-based beverages.[13]

- In partnership with Rainforest Alliance, Nestlé has implemented the global Grown Respectfully Ambition and the Farmer Connect Program to provide equipment and training to farmers.[14] The Nestlé Cocoa Plan (2015-2019) is Nestlé's way of helping create a better future for cocoa farmers, their families, and their communities in more than 32 countries.[15]

[10] https://www.chocosuisse.ch/wp-content/uploads/2017/06/Press-Release-Cocoa-Platform_E.pdf
[11] http://www.kraftheinzcompany.com/
[12] https://www.starbucks.com/responsibility/sourcing/coffee
[13] https://www.starbucks.com/responsibility/sourcing/cocoa
[14] ttps://www.nescafe.com/the-future-of-coffee
[15] http://www.nestlecocoaplan.com/better-cocoa/

- Big chocolate companies such as Mars, Ferrero, and Hershey have pledged to source cocoa beans only from sustainable, certified origins by 2020.[16] Mars Incorporated's approach to sustainable and responsible practices includes the commitment to purchasing 100% of 23 key raw material from sustainable sources through independent certification programs such us, UTZ certified, RA, Fairtrade International and Roundtable of Sustainable Palm Oil.[17] As of 2016, 50% of its processed cocoa is from certified sources. In 2010, as part of its Sustainable in a Generation program to eliminate GHG emissions from its operation, Mars publicly released a preliminary version of the cacao genome. Through its *Vision for Change* program in Cote d'Ivoire, Mars supported cocoa farmers through training and high-quality planting materials and fertilizers to help farmers triple their yields. In 2014, Mars launched its Deforestation Policy, which commits the company to act on deforestation in its supply chain.
- The Lindt & Sprüngli Group, a global leader in the premium chocolate segment, developed its Sustainability Strategy for the cocoa sector in 2009. The strategy's focus is the whole value chain, including sourcing, production, and consumption ("bean to bar" strategy), with a goal to achieve full traceability of cocoa beans through the supply chain by 2020. Progress made with this program is published on The Forest Trust (TFT) Transparency Hub platform.

b) Highly profitable, alternative land uses to coffee and cocoa

Higher land values due to urbanization often displace coffee cultivation areas. Notorious examples include Panama's Boquete and Chiriquí regions, the Central Plateau (*Meseta Central*) in Costa Rica, and Antigua in Guatemala (Schmitt-Harsh 2013).

c) *Landscape features*

Accessibility and proximity to market and to cities also influence land cover change. For instance, in Guatemala, areas with low altitude, flat terrain, and that are closer to existing croplands coffee agroecosystem were converted to croplands (Schmitt-Harsh 2013). In El Salvador, tree cover loss was linked to proximity to urban areas, with farms far away from coffee export markets more likely to be cleared (Blackman et al. 2012). In Costa Rica, the reduction of coffee cultivation areas and tree cover are directly related to the number of family members engaged in other agriculture and non-farm work (Bosselmann 2012).

d) Climate change

Global climate change alters the patterns of temperature and precipitation and shifts crop suitability patterns (Lin et al. 2008). Coffee and cocoa production are vulnerable to climate change (Schroth et al. 2016). It is expected that by 2050s, global temperatures will increase by 2°C together with some increased variability in precipitation.

For Arabica coffee, these changes will reduce climatic suitability at low elevations and increase suitability at higher altitude. Coffee farming will move up to higher elevations, threatening natural protected areas in mountain peaks and the headwaters of major rivers. The predicted changes in coffee suitability are directly linked to latitude. Farming Arabica coffee within 5°–10° of the equator and below 1000 m altitude will be less suitable to yields. Changes in annual precipitation and its seasonality would have little effect (Ovalle-Rivera et al. 2015). Examples of the effects of climate change by coffee producing region is summarized in Table 2. Some of the changes predicted in suitability are described in the following paragraphs.

[16] https://www.confectionerynews.com/Article/2013/01/17/Cocoa-crisis-unlikely-says-Euromonitor
[17] http://www.mars.com/docs/default-source/doing-our-part/principles-in-action/2015-summary/marspiasummary2015updated.pdf?sfvrsn=4

- ***Mesoamerica:*** Higher temperatures will move the climates suitable for Arabica coffee from the current 400–2000 m altitude to 800–2500 m. Nicaragua and El Salvador, without high mountains, will be most affected. Guatemala, Mexico, Honduras, and Costa Rica will gain suitability at elevations of 1500–2500 m. In Mesoamerica, 30% of coffee lands will become less suitable for cultivation. The largest losses are expected for Mexico (29%), and smallest losses are expected for Guatemala (19%).

- ***South America:*** The range of elevations suitable for Arabica coffee in the Andes is predicted to move from the current 500–1500 m to 1000–2800 m. Areas below 1800 m in all three countries will become less suitable. Peru, Colombia, and Ecuador, however, will gain some suitable areas at higher elevations. In Brazil, there will be a shift in suitable climates from the current 400–1500 m to 800–1600 m. Brazil has no high elevations and grows Arabica coffee at low elevations, which are predicted to become less suitable. Overall, Andean countries will lose 16–20% of the current area suitable for Arabica coffee while Brazil will lose 25%.

- ***India and Indochina:*** Suitable climates for Arabica coffee will shift upward from the current 400–1500 m above sea level to 700–1800 m. India and Laos will experience a loss of suitability below 1200 m. In Indonesia and the Pacific islands, suitable climates will also shift upward from the current 500–2000 m to 800–2300 m. Indonesia will likely suffer a reduction of 21%–37% in the area suitable to produce Arabica coffee, while Papua New Guinea, at higher elevations, would be less affected.

- ***East Africa:*** In East Africa, climates suitable for Arabica coffee are predicted to shift from 400–2000 m above sea level to 800–2500 m. There will be little change in suitability of the areas that currently grow Arabica in Ethiopia, Kenya, Rwanda, and Burundi. There may be gains in suitable land areas at higher elevations of 1500–2400 m. Tanzania and Uganda will lose suitable area at elevations below 1400 m. In South Africa and Madagascar, the suitable climates will shift upward from 500–1700 m to 700–2000 m, resulting in losses of suitable area at lower elevations. This is especially concerning for Zimbabwe as its growing areas are at low altitudes.

In the case of cocoa, a study conducted in selected countries predicts an overall decrease in the climatic suitability of the current growing regions of Ghana and Côte d´Ivoire, two big players in cocoa production. (Läderach et al. 2013). The most affected regions are expected to be the southern Brong Ahafo and Volta regions in Ghana and the Lagunes, Moyen Cavally, Marahoue and Haut Sassandra regions in Côte d'Ivoire. Parts of these areas will become marginal or even unsuitable for cocoa, while other parts will remain suitable. The Western Region of Ghana, currently the country's most important cocoa producing region, is predicted to suffer a reduction in climatic suitability over most of its cultivation area, especially in the south. Currently, the most important cocoa region of Côte d'Ivoire, Bas Sassandra, is predicted to become climatically more suitable over most of its area (Läderach et al. 2013). A similar study carried out in Nicaragua indicates that 80% of the current cocoa cultivation area is located under 300 m. By 2050, scholars predict a reduction in climate suitability across all altitudinal strata except those areas located in the range of 1200-1300 m (Läderach et al. 2012). For Colombian agriculture, predictions of the effect of climate change by 2050 show that, if no adaptation measures are put in place, 80% of the crops including coffee, cocoa, fruit and bananas will be impacted in more than 60% of their current area under cultivation (Ramirez-Villegas 2012).

Climate change modeling studies have demonstrated that there is often considerable spatial heterogeneity in the vulnerability to climate change within affected regions. This implies that local production losses can be compensated for through intensification and the expansion of production elsewhere (Schroth et al. 2016). In Indonesia, a modeling study of current and future climatic suitability for Arabica coffee suggests that local production decline could at least partly be compensated for by expansion into other areas. This study recommended the need for public and private sector policies to encourage the expansion of coffee farms into areas that will remain suitable over the medium term, that are not under legal protection, and that are already deforested, so that coffee farming can make a positive contribution to landscape restoration (Schroth et al. 2014).

Table 2. Projected Changes in Overall Land by 2050 for Coffee Production in Selected Countries

Country	Current potential area for coffee excluding protected area (ha)	Change in suitability by 2050 (excluding protected areas)
Costa Rica	216,500	-0.20
Guatemala	663,500	-0.17
Honduras	1,231,500	-0.27
Mexico	2,743,000	-0.29
Nicaragua	105,000	-0.25
Bolivia	491,500	-0.20
Brazil	11,877,000	-0.25
Colombia	1,897,000	-0.16
Ecuador	7,345,000	-0.20
Peru	739,000	-0.20
Burundi	49,500	-0.09
Ethiopia	3,509,500	-0.11
Kenya	955,000	-0.12
Rwanda	157,000	-0.09
Uganda	755,000	-0.25
Tanzania	1,571,000	-0.22
Zambia	1000	-0.09
India	211,000	-0.28
Vietnam	473,000	-0.25
Indonesia	2,274,000	-0.18
Papua New Guinea	1,431,000	-0.09
Total	**33,030,500**	

Source: Ovalle-Rivera et al. 2015

How to Promote Replacing Other Crops by Coffee and Cocoa Agroforestry Systems

Coffee and cocoa plantations may be the land use of choice when traditional crops are no longer financially competitive, when infrastructure conditions change, or when appropriate supporting policies are in place. This report provides eight examples below.

1. Shaded cocoa plantations were introduced in the 19^{th} century as replacement crop to United Fruit's banana plantations in the entire Mesoamerican-Caribbean region when the plantations were infested by the Panama disease (*Fusarium oxysporum* f. sp. cubense (Foc)) (Beer et al. 1998; Dahlquist et al. 2007; Somarriba 1993).
2. In the Ecuadorian Amazon, the construction of roads resulted in the deforestation of 20,000 ha of native forests to plant food crops and pastures. Ten years later, many pastures had been converted into shaded cocoa plantations, often near natural protected areas (Rudel et al. 2002, Rudel 2009).
3. In Bolivia, multi-strata, successional agroforestry systems with cocoa have been proposed as an alternative to slash and burn agriculture with food crops (Yana and Weinert 2001).
4. Shaded cocoa has been promoted by government agencies as an alternative land use in previously deforested areas. For example, in the south of Pará State (the second most important cocoa producer of Brazil after Bahia), 120,000 ha of cocoa agroforestry systems are to be planted by 2020 as part of a government initiative (Mendes and Reis 2013). The renewed interest in cocoa production is a response to three conditions: (a) a promising national and international cocoa market including the expectation of a global cocoa supply gap; (2) environmental policies/laws obliging land owners to reforest illegal cleared land with native trees including cocoa agroforests as a permissible crop for restoration; and (c) proper biophysical conditions such as soil fertility for growing cocoa (Schroth et al. 2015).
5. In Peru, the Cocoa Alliance initiative (PCA), a 4-year project initiated in 2012, encouraged 20,000 small and medium size cocoa growers from the Ucayali, San Martín, and Huánuco regions of the Amazon basin to cultivate shaded cocoa on previously deforested land (Nash et al. 2016).
6. Landscape restoration initiatives promote the replacement of degraded pastures and ecologically un-friendly crops with tree crops in agroforestry systems. Horizon 2020 (H2020) is the largest EU Research and Innovation program ever, commands a budget of nearly €80 billion over 7 years to 2020, and attracts leverage funding from private sector banks and land owners. H2020 promises to stimulate the re-introduction of trees and tree-based production systems on degraded landscapes.[18]
7. Restoration economics, an approach proposed by the World Resources Institute and The Nature Conservancy, creates a network of businesses, investors, and consumers to engage in financially and economically viable activities involving land restoration. The Initiative 20x20 was launched by WRI, TNC, CATIE, IUCN and other organizations. The African Forest Landscape Restoration Initiative, AFR100, has helped to mobilize more than USD$2 billion in commitments from investors in Latin America and Africa (Faruqi et al. 2018). An example of multi-stakeholder initiative in Brazil is presented in Box 3 below.
8. Government programs supporting the expansion or renovation of coffee/cocoa plantations also play an important role in increasing the presence of these crops in the landscape (PROECUADOR 2013).

[18] https://ec.europa.eu/programmes/horizon2020

Box 3. How to Implement Forest Landscape Restoration: An Innovative Approach

A multi-stakeholder initiative that seeks to restore degraded pastureland and to promote tree cover in agricultural lands is being implemented by The Nature Conservancy, Cargill, the Alternative Cooperative of Small Rural and Urban Producers, the Sao Felix Municipal Bureau of Agriculture, and the Ministry of Agriculture´s Cocoa Research and Technical Extension Agency in Brazil. The goal is to introduce cocoa-based agroforestry systems as an alternative to recover degraded pasturelands in an agricultural frontier zone. The process for the implementation of cocoa agroforestry systems involves the following activities:

- Property selection criteria (properties less than 300 ha, 40% of the deforested private lands in the Amazon are on plots of the range in area);
- Producer commitments;
- Technical assistance and agroforestry system implementation; and
- Scaling up of agroforestry systems through participatory demonstration units.

The selection of species involved discussions between technicians and a group of farmers. Accepted species were screened based on the following criteria: forest restoration, food security, market and profitability, competition between plants, family labor availability and/or needs, species lifecycle, species in demand, and random cultivation. The species selected were a mix of annual, first year crops (*Manihot esculenta*), fruit-bearing species (*Musa* sp, *Euterpe oleracea*), and timber trees (*Schinus molle* L., *Carapa guianensis*).

The program outcomes were significant. The initiative involved 61 farmers representing 5,000 ha. Deforestation in the farms varied from as low as 3% to as high as 99% of the entire property. A total of 284 ha (min = 1.5 ha and max = 10 ha per farm) of cocoa based agroforestry systems have been established. Companion trees/plants preferred in the cocoa system included *M. esculenta*, *Zea mays,* bananas, *Euterpe oleracea*, *Chrysophyllum cuneifolium* (Rudge) A.C.D., *Swietenia macrophylla, Copaifera* spp., and *Carapa guianensis*. The economic benefits of cocoa agroforestry systems compared to cattle ranching are estimated to yield annual net profits of USD$1,750 per ha with an average cocoa yield of 700 kg per ha^{-1}. The initiative provides evidence that cocoa agroforestry systems contribute to national low carbon economies, sustainable supply chain development, and zero deforestation country

Drivers, Recommendations, and Knowledge Gaps

A gamut of drivers stimulates farmers to clear natural forests, to plant coffee and cacao, to eradicate trees from the shade canopy, to replace coffee and cocoa plantations with other crops and pastures, and vice-versa (Table 3). The World Bank Group (WBG), governments, farmers, the coffee/cocoa industry, other value chain actors, donors, and financing institutions may use these recommendations to guide collective action to minimize deforestation and maximize reforestation within coffee/cocoa agroforestry systems. One or a few pilot projects in different agro-ecological and cultural contexts can help gauge and tailor solutions to the following key issues: (a) the improvement and enforcement of forest/environmental policies and laws including real-time monitoring of deforestation in forest areas threatened by the expansion of coffee and cocoa cultivation; (b) the design and validation of new models of sustainable intensification to achieve profitability with a low ecological footprint by optimally designing and transforming current shade canopies (typically shaded with non-commercially valuable legume trees) into valuable timber- fruit shade canopies; (c) the development and assessment of the impact of improved value chains on on-farm fruit and timber production; and (d) the development and testing of new governance mechanisms (e.g. multi-stakeholder partnership platforms) and financing mechanisms to scale up the retention, planting, and use of valuable trees in coffee/cocoa agroforestry systems. Pilot projects can be implemented under three key scenarios: (1) smallholder production systems using mixed shade; (2) medium to large, intensive production systems; and (3) rustic and successional agroforests in forest frontiers.

Table 3. Drivers, Recommendations, and Knowledge Gaps in the Four Transition Pathways between Forests and Coffee/cocoa Agroforestry Systems

Pathway	Drivers	Recommendations	Research gaps
How to avoid clearing the forest to establish coffee/cocoa plantations.	Unsupportive legal, institutional, policy, and financial frameworks for forests and tree tenure (especially timber) and human migrations Low financial value of forests to farmers Timber concessions and the construction of roads	Improve the legal, institutional, policy, and financial frameworks to avoid forest clearing. Promote and support industry pledges for moratoria on trading commodities associated with deforestation. Support zero deforestation pledges, and certified sourcing efforts by industry and other value chain actors. Design and finance instruments to pay farmers for the ecosystem services natural forest provide to global society. Embrace global conventions and declarations and embed them in national and jurisdictional sub-sectoral (coffee/cocoa) plans and goals. Promote and support the use of modern technology to monitor deforestation in real time. Support law enforcement in protected forest areas.	How do we increase the financial value of the forest? What financial mechanisms are required to compete with traditional financing mechanisms for other agricultural land uses? What are the best governance and multi-stakeholder partnerships for different geographies, cultures, and socio-economic farming typologies?

How to counter the growing appetite for full sun coffee and cocoa and retain shade canopy trees.	Low coffee/cocoa yields and profitability of successional agroforests and rustic/cabruca systems due to excessive shade motivate farmers to replace these systems by other crops and pastures or transform them into other typologies with lower tree canopy cover. Crop husbandry intensification to increase crop yields comes along with a reduction in shade levels (reduction in standing biomass or carbon). Use of improved crop genetics, pest/disease outbreaks, and use of inorganic fertilizer usually lead to reductions in shade levels. Unsupportive legal, policy, and institutional frameworks for trees on farms. Trees (especially timber) are invisible and not included in development programs nor in the portfolio of best practices and extension service for farmers. On-farm timber trees are usually over-regulated, forcing farmers to harvest and use their trees in illegal channels with lower prices and higher costs and legal risks. Farm timber and fruit value chains under-developed. Most on-farm fruit production lost to rot.	Development of gourmet and niche markets for coffee/cocoa collected from wild successional agroforests and rustic/cabruca systems. Support payment schemes rewarding farmers for conserving wild biodiversity at both the farm and landscape levels. Develop sustainable intensification approaches that preserve trees in the shade canopy. Use behavioral economics to understand farmer preferences, aversions, and attitudes toward planting trees in their coffee/cocoa farms to enhance adoption. Aim at creating a culture among farmers to consider timber trees as crops (requiring proper management to fully reap their benefits to livelihoods and environment) instead of simply a resource that "nature provides" and is not to be managed or cultivated. Design and enforce supportive legislation (e.g. tenure rights), policies, and financial mechanisms to stimulate farmers to plant timber and other valuable trees in their coffee/cocoa farms. Simplify regulations and procedures to harvest, transport and use farm timber. Support certification schemes promoting the use of trees in coffee/cocoa agroforestry systems (e.g. bird friendly, sustainable, timber trees planted in coffee/cocoa farms, etc.). Support the development of value chains for on-farm fruit and timber production.	How to optimally intensify successional cocoa agroforests without losing their "wild" nature? How to optimally design coffee/cocoa shade canopies to minimize trade-offs between crop husbandry intensification for high yields while maximizing the retention of trees in the shade canopy? Coffee and cocoa varieties and clones adapted to low light levels should be identified, tested under various agroforestry designs, and delivered to farmers. How to minimize trade-offs between high shade (carbon or biomass) levels, crop yields and species richness? How to optimally manage the synergies and trade-offs between climate change, global warming, water deficits, crop yields, and shade management? How to make farmers think of their trees as crops that need to be optimally managed? How to make trees visible to legislators, policy makers, development planners, financial institutions, extension services, and farmers? Develop science-based evidence that crop husbandry intensification is incompatible with the use of regulated tree shade canopy. Test the hypothesis that "there is a tree shade canopy with the right selection of tree species, proper planting density, and tree management compatible with high yields of coffee/cocoa." Provide evidence that crop intensification does not lead farmers to grow more intensively managed coffee/cocoa in their farms, but instead to allocate "freed" land to the development of natural forests.

			Provide science-based evidence that the production of timber and non-timber forest products in coffee/cocoa agroforestry systems reduces pressure on natural forests. Understand the economic behavior of farmers regarding the use of shade trees to increase the adoption of improved agroforestry practices.
How to avoid declining coffee and cocoa areas to the benefit of other crops.	Low profitability and high financial risk of coffee/cocoa farming due to price volatility, crop yield losses to pest/disease outbreaks, increasing labor costs, and low income from timber, fruit, firewood and other valuable goods from the shade canopy. Climate change: less rainfall (cacao) and higher temperatures (coffee) cause shifts in production zones and wild fires. Re-establishment of coffee/cocoa plantations after fire is expensive and farmers choose to plant other crops and pastures. Long-term loss of soil fertility due to continuous cultivation without fertilization to replenish soil nutrients (cocoa) cause low crop yields and the rising costs and feasibility of renovation of the coffee/cocoa plantation. New and more profitable land use alternatives (e.g. urbanization) become available in coffee/cocoa growing areas, stimulating land use change.	Increase the profitability of coffee/cocoa farms through: 1. Sustainable intensification of crop husbandry (better genetics, fertilizers, plant protection measures, agroforestry); 2. Valuing fruits and timber from shade canopies; 3. Improving the value chains of on-farm fruit and timber production; 4. Increased market prices of coffee and cocoa and reduced price volatility through certification (quality, environment, origins, social, etc.); and 5. Payment of ecosystem services rendered by shaded coffee and cocoa agroforestry systems Support industry and value chain efforts to secure sustainability through partnerships and multi-stakeholder platforms. Adopt strategies to cope with climate change.	How to increase the positive impact of product diversification (timber, fruit, and other goods and services) from shade canopy trees on the financial risks and vulnerability of the household/enterprise? How to increase the use of low-cost mechanization to reduce labor costs and increase profitability?

How to promote replacing other crops by coffee and cocoa agroforestry systems.	Low profitability of crops and degraded pastures coupled with support from governments, NGOs, the private sector, and donors supporting the expansion of the cultivation of coffee and cocoa.	Demonstrate the profitability of coffee and cocoa agroforestry systems. (See above.)	Assess the impacts of global changes (climate, economic globalization, commodity trends, etc.) on the resilience of coffee/cocoa agroforestry systems. Investigate the role of coffee and cocoa agroforestry systems in supporting biodiversity conservation both at the plantation site and at the landscape scale (biological connectivity in the agricultural matrix).

Conclusions

Coffee and cocoa are drivers of both deforestation and reforestation. Coffee and cocoa plantations may be established following four different pathways. For instance, pristine forests may be totally cleared, and the land planted to various forms of open-sun agriculture land or pastures. These may eventually be transformed into coffee or cocoa plantations. Alternatively, forests may be directly transformed into any of six different coffee and cocoa shade canopy typologies depicting a gradient of decreasing tree cover as a surrogate for shade levels and increasing crop yields. Finally, coffee or cocoa plantations may be cleared to plant open-sun agriculture or pastures. Alternatively, degraded open sun crops and pastures may be converted into coffee and cocoa agroforestry systems. Transition pathways are not linear in time or in space. To reduce the deforestation footprint and to increase the reforestation impact of coffee and cocoa agroforestry systems, we must take various courses of action.

Deforestation caused by the expansion of coffee and cocoa cultivation can be tackled by using a wide range of interventions, but two stand out.

1) Improve the legal, institutional, policy, and financial frameworks to increase the value of forests on private land and to enforce protection measures on public conservation areas, including investment in the use of modern technologies to monitor land use changes in real time.

2) Support industry and value chain measures aimed at sourcing only from certified origins not linked to deforestation areas, help enforce zero-deforestation pledges, and support multi-stakeholder platforms involving farmer organizations, national and jurisdictional governments, middlemen, exporters, manufacturers, and financing institutions aimed at reducing deforestation and securing sustainable coffee and cocoa economies. Worth mentioning is the Cocoa and Forest Initiative recently launched by a conglomerate of 32 major chocolate companies and the governments of Cote d'Ivoire and Ghana, the world's largest cocoa producers.

Reforestation with coffee and cocoa agroforestry systems has three components: (a) retaining trees in the shade canopy; (b) avoiding losing coffee and cocoa areas to open sun crops and pastures; and (c) replacing open sun crops and degraded pastures with coffee and cocoa agroforestry. Key recommendations to benefit from these components include:

1) Increasing the profitability of coffee and cocoa farming by implementing a range of good agricultural, post-harvest practices, and value chain interventions such as certification. Almost every major chocolate company has launched programs to support a sustainable cocoa economy with pledges to source only from certified origins. Most programs operate through multi-stakeholder platforms involving farmers, chocolate companies, traders, governments, financing institutions, and donors to achieve profitability and to reduced environmental footprints.

2) Optimizing the trades-off between the ''use of new cocoa genotypes combined with high external inputs to increase cocoa yield'' and the ''reduction in shade level (tree cover) and species richness''.

3) Improving the legal, institutional, policy, and financial frameworks to make trees in the shade canopy more "visible" to farmers, extension services, policy makers, development planners, and financial institutions. Among farmers, promote the vision of "timber trees as crops" that need proper management to fully realize their production potential for both livelihoods and the environment. Ensure farmers have property rights on trees they manage and used without legal complications and operational difficulties. Good examples include the Honduran government decree allowing the national coffee institute to certify the planting of timber trees on coffee farms to facilitate harvesting and utilization. Similar experiences involve FEDECAFE in Colombia, and the Forest Law in Guatemala that support

smallholder to plant trees in various agroforestry modalities. The certification of trees planted in cocoa farms has been suggested for Africa.

Concerted actions between national and jurisdictional governments, industry, other value chain actors, farmers, financial institutions, and donors are essential to address the many facets of this central question: *how to simultaneously minimize the deforestation footprint of coffee/cocoa cultivation while increasing its role as an agent of reforestation?* The drivers, recommendations, and knowledge gaps identified in this report are common to most, if not all, coffee and cocoa producing countries in Asia, Africa, and Latin America.

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Annex 1. Coffee and cocoa shade canopy typologies

In what follows we present a summary description of the six shade canopy typologies, their major limiting factors, and threats to the retention of trees.

a) Successional coffee/cocoa agroforests

Successional agroforests are the most "forest-like" coffee and cocoa agroforestry systems. Despite their appearances, a closer analysis demonstrates the drastic changes in biomass, botanical composition, and structural complexity of the original forest as well as the socio-economic pressures that limit their widespread use in Latin America and Africa. (Boxes 1 and 2).

Photo 3: Successional Cocoa Agroforest in the Bolivian Amazon.

Source: Windson July, CATIE

Virtually nothing is known about the structural complexity, management, and yields of the successional cocoa and coffee agroforests of the Amazon and Ethiopian forests, respectively. (Somarriba and Lachenaud 2013; Takahashi and Todo 2014). Successional cocoa agroforests, known as *cacaguales or chocolatales* in their native South American region of origin, supplied part of the European demand for cacao and chocolate in the 17th and 18th centuries (Clement et al. 2010; Patiño 2002; Bazoberry Chali and Salazar Carrasco 2008). Extraction of wild Amazonian cocoa from the *chocolatales* practically disappeared in the 19th and 20th centuries, but at the beginning of the 21st century there was renewed commercial interest in Amazonian extractive cocoa. Consumers of gourmet chocolates are looking for new, exotic cocoa flavors, fueling a new cycle of domestication and management intensification that opens opportunities for the economic development of local economies, but also poses new threats to the conservation of this "wild cocoa agroecosystem." In 2013, the Government of Bolivia declared (Law No

438 Article 1) the protection of “wild” cocoa areas, the promotion of cocoa agroforestry system for cultivation, and the development of denomination of origin for the Bolivian “wild” cocoa as national interests. How and to what degree it is possible to intensify the management and domestication of the cocoa agroforest without losing its “wild” nature it is not known. Pathways leading to the creation of *chocolatales* have been enumerated (Somarriba and Lachenaud 2013). Coffee agroforests analogous to the Amazonian cocoa agroforests can be found in Ethiopia (Takahashi and Todo 2014). Cocoa and coffee agroforests are analogous to the Indonesian rubber and damar agroforests (De Foresta and Michon 1996).

b) Cabrucas and rustic coffee systems

Cabruca is the traditional form of cocoa cultivation in Southern Bahia, Brazil, covering approximately 600,000 ha. Cabrucas are characterized by the planting of cocoa trees underneath selectively thinned natural forest. Despite their forest-like physiognomy, cabrucas are highly modified in structure and composition in comparison to natural forest and many forest climax tree species are not capable of reproducing their populations in the cabruca environment (Sambuichi 2002; Rolim and Chiarello 2004). However, even with these shortcomings, cabrucas are one of the best alternatives for the conservation of wild biodiversity in the highly fragmented landscape of Southeastern Brazil (Johns 1999).

Low cocoa yields are typical in the cabruca production system. When cocoa prices go up or pest outbreaks hit the region, crop husbandry intensification is recommended and extension services prompt farmers to use low shade levels and apply inorganic fertilizers and other agrochemicals to achieve up to a four-fold increase in cocoa yields. Despite these pressures, cabrucas have persisted in the landscape as farmers are not entirely convinced of the benefit of shade removal (Johns 1999). However, a portion of the cabrucas are eliminated every year and replaced by less friendly land uses such as cattle ranching and logging. Positive shifts in sector policies, the recognition of the cabruca system as an environmental tool, and the evolution of tourism has contributed to the conservation of this friendly agroforestry system (Ruf and Schroth 2004). The role of cabruca agroforestry systems in connecting forest patches and as habitats for the golden headed lion tamarins (*Leontopithecus chrysomelas*) has been pointed out by several authors (Zeigler 2011). Up to 18% of the total range of forest cover available to emblematic wild animal species are cabrucas.

Photo 4: Cabruca Cocoa in Bahia, Brazil

Source: RHR Sambuichi, Brazil

Growth and expansion of coffee production in Mexico between 1970-1992 had a profound effect on the environment as it replaced traditional cocoa, tobacco, sugar cane and orange farms (Philpott et al. 2008; Nestel 1995). Colonization fronts and the expansion of coffee also replaced tropical montane forests in Chiapas and Oaxaca, the two most important coffee-producing states in Mexico (Revel-Mouroz 1980). It is estimated that between 75% and 54% of the rainforest in Oaxaca and Chiapas, respectively, were affected or displaced by coffee cultivation (Moguel 1995). Nowadays, coffee covers 800,000 ha and employs 282,000 producers (Hernández-Martínez et al. 2009). It is estimated that 89% of the total coffee area is managed under some shade, with 38% of the cultivated areas grown under a multilayered canopy shade know as a rustic and mixed-shade coffee canopy (Moguel and Toledo 1999). (Box 1)

Box 1. Rustic Coffee in Mexico

Characterizations of rustic coffee plantations in Chiapas, Mexico showed that this system is more than 50 years old with low-medium coffee density that averages 1300 plants ha^{-1} and ranges from 374–3624 plants ha^{-1}). These plantations had high tree cover at 70%-100% and high tree diversity with more than 50 species per ha^{-1}. Rustic coffee yields are approximately 25% lower than that of conventional plantation (Jezeer et al. 2017; Jha et al. 2014). High plant and bird diversity(between 90 and 120 plant species) has been recorded on rustic coffee and mixed-shade coffee plantations with 70% of tree cover (Bandeira et al. 2005;Greenberg et al. 1997; Moguel and Toledo 1999; Perfecto et al. 2005). Shade tree density estimates in the Chiapas rustic systems averaged 457 trees ha^{-1}. Half of these were fruit-tree species including oranges and bananas. (Romero-Alvarado et al. 2002). Rustic and mixed-shade coffee plantations are now valued for their contributions to reduced pressure over the remaining montane forests within a region of high population density, good road networks, and widespread cattle ranching (Toledo-Aceves et al. 2011). Rustic coffee also provides products and benefits to farmers that justified its suitability as an alternative land use for sustainable rural development (Perfecto et al. 2005; Tscharntke et al. 2015). Rustic coffee is credited for stocking significant amounts of carbon and hence having the potential to mitigate climate change at the landscape levels (Harvey et al. 2014; Tscharntke et al. 2015). Polyculture-shade organic coffee systems can accumulate up to 167.4 Mg C ha^{-1} (Soto-Pinto et al. 2010).

c) Mixed shade, productive shade, and shade-only systems

In Central America, Mexico, Venezuela, and Colombia the use of shade trees, especially leguminous trees, was a common practice among coffee farmers. This practice was directly influenced by cultural beliefs from prehistoric agricultural communities (Cook 1901). The use of shade in pre-Columbian cultivation of cocoa can also be demonstrated (Johns 1999). An inventory of cocoa trees in Mayan households in Soconusco, Chiapas, Mexico conducted in 1528 describes two production modes: species-diverse shade in smallholder orchards and simple-shade in larger plantations (Gasco 2006). Chiefs and other indigenous authorities, and later the Spanish colonists, planted cocoa under the shade of *Gliricidia sepium*, with cocoa trees regularly planted at 3 x 3 or 4 x 4m spacing in deforested sites. These sites were drained, irrigated, pruned, thinned, and regularly harvested (Touzard 1993). These two modalities of cultivating cocoa persist today.

d) Open sun, no-shade systems

Open sun, no-shade cultivation of cocoa is prevalent in Cote d'Ivoire, Ghana, Ecuador, Brazil, and Indonesia (Tondoh et al. 2015). (Box 2) No-shade coffee is prevalent in Brazil, Colombia, and Costa Rica. These systems are characterized by the use of improved crop genetics, high planting density, heavy use of fertilizers, high yields, and large farms owned by wealthy farmers. This production model has been also recommended to smallholder farmers, but adoption has been limited due to a lack of capital to purchase inputs and the inherent financial risk associated with price volatility of both coffee and cocoa (Donald 2004; Johns 1999; Millard 2011; Obiri et al. 2007).

Photo 5: Open Sun, No-shade Coffee Plantations in Heredia, Costa Rica

Source: Eduardo Somarriba, CATIE, Costa Rica.

Box 2. Intensive Cocoa Farming: The Case of Ecuador

Historically, cocoa was Ecuador's most important export, with large expanses of the coastal region devoted to its cultivation (Bentley et al. 2004). Ecuador emerged as the world's largest cocoa growing country, producing between 30-50% of world cocoa throughout the 19th century (Griffith 2004). The prominence of Ecuador in the supply of cocoa beans retreated in the 20th century, but, in 1971, the government offered tax exemption incentives to stimulate the cultivation and agroindustry of cocoa (Williamson 2002). After Brazil, Ecuador is now the second largest producer of cocoa beans in Latin America, with a sizeable 0.5 million ha currently under cultivation and high yield averages due to the wide spread use of high yielding clones, no-shade, and intensive crop husbandry.

Two different cocoa production systems can be found in Ecuador: The first includes large commercial plantations that cultivate under full sun and that intensively manage modern, high yielding clones such as CCN-51 (Boza et al. 2014). The second includes small to medium size shaded agroforestry systems with lax crop husbandry, hybrid cocoa, and a fine cocoa variety known as *cacao nacional*. Full-sun, modern plantations account for nearly 80% of the total cultivated area (INEC 2015). Although full sun intensive systems are more profitable, smallholders continue to cultivate shaded cocoa systems due to the related environmental benefits, access to market niches, premium prices, as well as access to timber, food and medicinal plants (Waldron et al. 2012; Bentley et al. 2004; Blare and Useche 2013; Mussak and Laarman 1989). Cocoa yields is 1.5 times higher in intensively managed monocultures than in cocoa agroforestry (Jadán et al. 2015).

Photo 1: Cocoa-timber (*Terminalia ivorensis*) in Honduras

Source: Jesus Sanchez, FHIA

Shaded coffee and cocoa agroforestry systems are known to play a significant role in maintaining tree cover as well as a role in providing livelihoods and increased financial resilience to smallholder farmers. Farmers retain and plant a large number of tree species to provide shade and shelter and to help sustain high coffee/cacao yields (Anglaaere et al. 2011; Koko et al. 2013; Somarriba and Beer 2011), to produce timber, fruits, and other goods for family consumption or sale (Albertin and Nair 2004; Awono et al. 2002; Deheuvels et al. 2012; Rice 2008; Somarriba 2007; Jezeer et al. 2018; Pinoargote et al. 2017; Somarriba et al. 2017; Sonwa et al. 2014); to generate income (Cerda et al. 2014; Oke and Odebiyi 2007); to manage financial risks and family vulnerability (Godoy and Bennett 1989; Jezeer et al. 2018a,b; Ramírez et al. 2001; Gordon et al. 2007; Mehta and Lauschner 1997; Padron and Burger 2015; Vaast et al. 2015); to conserve biodiversity at the plot and landscape levels (Clough et al. 2011; de Beenhouwer et al. 2013; Stenchly et al. 2012; Tscharntke et al. 2015); to enhance the pollination of cocoa (Frimpong et al. 2011; Toledo-Hernández et al. 2017); to sustain soil fertility (Moço et al. 2010; Mortimer et al. 2017); to store carbon (Dawoe et al. 2016; Norgrove and Hauser 2013; Oke and Olatiillu 2011; Saj et al. 2013; Somarriba et al. 2013); and to reduce farmers' vulnerability to the effects of extreme climatic events (Läderach et al. 2013; Lin 2007; Schwendenmann et al. 2010).

Photo 2: Fruits from Cocoa Shade Canopies in Central America

Source: Rolando Cerda, CATIE

Timber production in coffee and cocoa agroforestry systems is still a yet un-realized potential. Standing timber in the coffee and cocoa shaded systems of Honduras and Nicaragua range between 13.4 to 82.7 m^3 ha^{-1}. Despite lower market prices, timber sales represented between 11%–49 % of the total revenue from coffee and cocoa systems. By improving basic silviculture, the contribution of timber sales to total revenues from shaded coffee and cocoa plantations can increase up to 58% (de Sousa et al. 2015; Pinoargote et al. 2017). Similar results have been published for timber stocks on coffee plantations in Costa Rica, Peru, Guatemala, and Mexico (Somarriba 1990; Jezeer et al. 2018; Peeters et al. 2003; Rice 2008; Vaast et al. 2015). In Costa Rica, naturally regenerated *Cordia alliodora* on cocoa plantations stocks 44 m^3 ha^{-1} of standing commercial timber. This is equivalent to USD$2,633 ha^{-1} in family savings that can be realized at times of hardship or to cope with un-expected needs thereby reducing the financial vulnerability of the household. The *Cordia alliodora* stocks on plantations have a growth rate of 4.43 m^3 ha^{-1} per year, equivalent to an annual income of US$ 265 ha^{-1} per year (Somarriba et al. 2014; Somarriba and Beer 2011). Damage to coffee or cocoa caused by the harvest of timber trees should not be a major concern to farmers and extension workers (Somarriba 1992; Ryan et al. 2009). In African cocoa producing countries, unsupportive legislation is a strong deterrent to farmers to retain or plant timber trees. Trees in forests belong to the state, so farmers have no interest in keeping them when converting the forest into cocoa plantations. Farmers also fear that loggers, with or without permits from the local authorities, will cut down trees on their farm, causing damage to the cocoa without compensation. Changes in the legislation in Ghana and Cote d'Ivoire now give farmers ownership of planted timber trees, but farmers still fear being unable to prove that they planted the tree (especially native species), prompting them to favor planting exotic over native species (Ruf and Varlet 2017).

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