Trade-offs between crop intensification and ecosystem services: the role of agroforestry in cocoa cultivation

Philippe Vaast · Eduardo Somarriba

Received: 24 October 2014 / Accepted: 31 October 2014 / Published online: 8 November 2014
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Abstract Research published in this special issue on cocoa agroforestry illustrates the multifunctional role of shade trees for sustaining cocoa production and improving farmers' livelihoods, and addresses trade-offs between higher cocoa yield and the provision of ecosystem services to local households and global society. Indeed, the use of diverse shade in cocoa cultivation is threatened by a new drive towards crop intensification. The removal of shade trees diminishes smallholders' ability to adapt to global change driven by demographic pressure, food insecurity, cocoa price volatility and climate change. Some forms of crop intensification may reduce ecological resilience of cocoa production systems, making adaptation strategies, combining shade trees with innovative management practices, essential for sustaining cocoa yield. Managing trade-offs between yield and environmental services at the cocoa plot and landscape scales requires a multi-disciplinary approach to identify key

management options that goes beyond the artificially polarized debates around intensified versus traditional agroforestry practices, or more generally, land-sparing versus land-sharing strategies. The global challenge facing the cocoa sector today is how to increase cocoa production to meet growing demand, without expanding the area under cocoa. This means finding sustainable ways to maintain cocoa production within today's producing regions, particularly West Africa, through a series of technical innovations geared towards smallholders. Inappropriate intensification may result in heavy deforestation on new pioneer fronts, such as the Congo basin, and existing cocoa being replaced either by other agricultural commodities, or by less resilient and less environmentally friendly production practices.

Keywords Agroforestry · Cocoa · Intensification · Smallholders' livelihoods · Revenue diversification · Shade

P. Vaast (✉)
ICRAF, United Nations Avenue, Gigiri,
P.O. Box 30677, Nairobi 00100, Kenya
e-mail: p.vaast@cgiar.org; philippe.vaast@cirad.fr

P. Vaast
CIRAD, UMR Eco&Sols - Ecologie Fonctionnelle &
Biogéochimie des Sols & Agroécosystèmes, 2 Place
Viala, 34060 Montpellier cedex 2, France

E. Somarriba
CATIE, 7170, Cartago, Turrialba 30501, Costa Rica
e-mail: esomarri@catie.ac.cr

Cocoa livelihood and environment trade-offs

It is estimated that over 80 % of cocoa comes from 7 to 8 million small, family-managed cocoa farms worldwide (FAO 2014). The typical farm covers 0.25–5 ha, yielding 300–600 kg ha⁻¹ year⁻¹ of cocoa beans in Africa and the Americas and about 500–700 kg ha⁻¹ year⁻¹ in Asia (FAO 2014). Yield varies not only across region (Fig. 1a), but also within country and according to cocoa

Fig. 1 Evolution over time of (A) cocoa yield (kg/ha) in Africa, Asia and America; and areas (in millions of Ha) and production (in millions of tons) in Africa (B), Asia (C) and America (D) based on FAO data (FAO 2014)

systems (Deheuvels et al. 2012; ICCO 2014a; World Cocoa Foundation 2014). Cocoa grown in multi-strata agroforestry systems provides livelihoods for farmers and ecosystem services at local and global scales (Cerdá et al. 2014; Rice and Greenberg 2000). Worldwide, it is estimated that around 70 % of cocoa is cultivated with various levels of shade (Gockowski and Sonwa 2011; Somarriba et al. 2012).

Although cocoa yield has stagnated over the last few decades (Fig. 1A), world cocoa production has doubled, mostly through extension on pioneer fronts with shifts in cocoa producing areas between continents and within countries (Fig. 1B, C, D). Cocoa cultivation on pioneer fronts has led over the last five decades to the disappearance of 14–15 million ha of tropical forests globally (around 2 million in Cote d'Ivoire, 1.5 million in Ghana and over 1 million ha in Indonesia) with around 10 million ha currently in production (Clough et al. 2009).

Demand for cocoa beans is steadily growing at 1 % annually, and consequently the industry is promoting the intensification of cocoa cultivation in order to

secure supply (Blommer 2011; ICCO 2014a). Historically, intensification to achieve higher crop yields in both coffee (Vandermeer 2011) and cocoa (Ruf 2011; Wade et al. 2010) has brought about a reduction in both shade levels and species richness. Recent international fora have emphasized the need to intensify cocoa cultivation through the use of improved genetic material and agricultural practices based on the use of agro-chemicals, especially inorganic fertilizers (17th International Cocoa Research Conference, Yaoundé, Cameroon, 15–20 October 2012; 33rd World Cocoa Convention Congress, Abidjan, Cote d'Ivoire, May 7–11, 2014).

Concerns with respect to the negative impacts of such intensive management on the livelihoods of rural cocoa communities, the conservation of natural resources and the provision of ecosystem services have not been properly addressed. This is unfortunate because cocoa farmers obtain timber, fruits and other valuable goods from shade trees to sustain their livelihoods and to better resist shocks such as decreasing and/or fluctuating cocoa prices in

international markets, or pest and diseases outbreaks (Bentley et al. 2004; Cerda et al. 2014; Duguma et al. 2001). A botanically diverse and ecologically complex shade canopy also has positive impacts on the conservation of biological diversity at both plot and landscape levels (Schroth et al. 2011), carbon sequestration (Schroth et al. 2014; Saj et al. 2013; Somarriba et al. 2013), and provision of other ecosystem services (Anglaaere et al. 2011; Smith Dumont et al. 2014).

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” in order to minimize negative impacts on the provision of both livelihoods for farmers and ecosystem services for society (Steffan-Dewenter et al. 2007).

This editorial for the special issue on cocoa agroforestry sets out to: (1) place current cocoa production practices in their historical context; (2) outline the key issues around cocoa intensification that is resulting in a reduction of shade trees today; and (3) summarize how the results reported in articles in this special issue address the tradeoffs between higher cocoa yield and the provision of ecosystem services to local households and global society.

Domestication and intensification of cocoa

Domestication of cocoa began around 8,000 years ago, in the foothills of the Andes, along the banks of major upper tributaries of the Amazon River in what is today Bolivia, Peru, Ecuador, and Colombia (Clement et al. 2010; Miller and Nair 2006; Thomas et al. 2012). Native Amazonians collected ripe cocoa pods from fruiting trees found in patches embedded within the forest matrix in the high terraces of the riverine system, and transported them back to their villages for home consumption. Cocoa pods were consumed as fruit by sucking the pulp and spitting out the seed, or were fermented to produce an alcoholic drink (Henderson et al. 2007). Early selection for desirable traits such as abundant and sweet pulp probably occurred (Thomas et al. 2012).

Cultivation of cocoa, as distinct from its extraction from cocoa agroforests, started in Mexico 4,000 years ago, with the Olmecs, who fermented the seeds with the sweet pulp to produce an alcoholic beverage, and eventually roasted the beans and discovered chocolate

(Henderson et al. 2007). Cocoa was cultivated under two management systems: smallholder cultivation and larger plantations. Indigenous smallholders planted cocoa either in their backyards or in association with other crops under a diverse shade canopy including fruit trees (Touzard 1993). Chiefs and other indigenous authorities, and later the Spanish colonists, planted cocoa under the shade of *Gliricidia sepium*, with trees regularly planted at 3×3 or 4×4 m spacing, in deforested sites, with drainage or irrigation, pruning and thinning, and regular harvest (Touzard 1993). An inventory of cocoa trees in Maya households in Soconusco, Chiapas, Mexico was conducted as early as 1528 (Gasco 2006). These two production modes, smallholders and plantations, remain today.

With the introduction of chocolate to Spain in the sixteenth Century and the expansion of the European market for chocolate, there were attempts to satisfy Spanish domestic demand by planting cocoa in Spanish territories such as the Dominican Republic, Trinidad, Venezuela and Haiti, but initially without much success. More successful were the Spanish Capuchin friars, who started growing Criollo cocoa in Ecuador around 1635. The rush by European mercantile nations to claim land to cultivate cocoa began in earnest in the late seventeenth century. France introduced cocoa to Martinique and Saint Lucia (1660), the Dominican Republic (1665), Brazil (1677), the Guianas (1684) and Grenada (1714); England promoted cocoa cultivation in Jamaica by 1670; and, prior to this, the Dutch had taken over plantations in Curaçao when they seized the island in 1620. The explosion in demand brought about by chocolate's affordability required yet more cocoa to be cultivated. Amelonado cocoa from Brazil was planted in Principe in 1822, Sao Tomé in 1830 and Fernando Po in 1854, then in Nigeria in 1874, Ghana in 1879 and Côte d'Ivoire in 1890. The race for the intensification of cocoa cultivation took off.

Cocoa cultivation practices today

Worldwide, cocoa is produced mostly by smallholders with little capital, hence low investment capacity for technical innovation. This results in low yields and farmers highly exposed to cocoa price volatility, and vulnerable to pests and diseases outbreaks as well as

the effects of climate change (Läderach et al. 2013). Low cocoa yields can be attributed to: pests and diseases, low levels of fertilization and the genetic potential of material planted. Key pests and diseases include mirids (*Sahlbergella singularis* and *Distantiella theobroma*) and the cocoa pod borer (*Conopomorpha cramerella*) in Indonesia, black pod (*Phytophthora palmivora* and *P. magakarya*) in West and Central Africa, monilia (*Moniliophthora roreri*) and witches' broom (*Moniliophthora perniciosa*) in America. Soil fertility decline, especially in the absence of organic matter and fertilizer addition over the 20–30 years following forest clearing, has been highlighted as one of the major causes of declining cocoa yield (Gockowski et al. 2013; Tschardt et al. 2011).

The use of superior genotypes is essential for increasing cocoa yield, limiting incidence of pests and diseases, and producing high quality chocolate. In Africa, especially Ghana, cocoa farming largely relies on hybrids sexually propagated in seed gardens. In Asia, production is based on the use of grafted cocoa as well as hybrid material. In America, most of the current commercial stock is hybrid, but there is a clear trend to more widespread use of clonal cocoa, mostly grafted onto rootstock and rooted-stakes of selected clones adapted to local conditions (INGENIC 2009). To limit damage from pests and pathogens, commercial farmers in Ecuador and Brazil are planting “high-tech” cocoa in dry regions (around 1,000 mm year⁻¹), in full sun, with irrigation, heavy inorganic fertilization, and the use of high yielding clones (Boza et al. 2014). In Africa, governmental institutions and the industry are encouraging farmers to increase cocoa yield by using inorganic fertilizers in their cocoa fields. This recommendation to rely more on inorganic fertilizers also applies to cocoa production in America, where most small farmers do not fertilize their cocoa plantations. Only large cocoa farmers (>30 ha) regularly use inorganic fertilizers. The cocoa genome was mapped and published just a couple of years ago (Argout et al. 2011) and many researchers are now improving tissue culture and other asexual propagation techniques and developing protocols to manipulate and transfer genes (Guiltinan et al. 2008). Conflict between advocates of genetically modified cocoa and their opponents can be anticipated.

Shade trees and their contributions

Perennial crops such as cocoa or coffee are cultivated in a continuum of farm types, ranging from those based on the collection of pods or berries in their native environment, through rustic systems, mixed shade canopies, productive shade (e.g. tree crop–fruit tree or timber combinations), very specialized shade (e.g. coffee–legume), and finally to full sun cultivation. Production typologies along a gradient of intensification have been proposed for both coffee (Moguel and Toledo 2001) and cocoa (Somarriba and Lachenaud 2013). Intensification has negative impacts on the conservation of associated biodiversity, but despite this general trend, cocoa agroforestry systems do conserve planned (or planted) and associated (wild) biodiversity, at both the plot and landscape scales (Vandermeer 2011; Sambuichi 2006; Rolim and Chiarello 2004).

Deforestation and shade removal in cocoa systems have occurred largely on forest pioneer fronts that have a global importance for biodiversity conservation. This has prompted the development of various certification schemes that include shade criteria to give farmers higher prices and stable markets for coffee and cocoa produced under a variety of “sustainable” schemes (Bird-friendly, Fair Trade, Rainforest Alliance, UTZ Certified, etc.). Eco-certification schemes principally operating through the Sustainable Agriculture Network (SAN 2014) have set shade management criteria which require cocoa farmers to maintain a shade cover of 40 % provided by a minimum of 12 native species per ha (out of a list of 19 species for Cote d'Ivoire and Ghana) and with tree canopies comprising at least two strata. About 20 % of world cocoa produced today is eco-certified (ICCO 2014b), including 13 % by Rainforest Alliance that has certified more than 927,000 ha, mostly in Côte d'Ivoire, Ghana and Indonesia (SAN 2014). Several studies have been published recently to determine the conditions that make certification a financially viable option to retain biodiversity while at the same time achieving high cocoa yield (Gockowski et al. 2010, 2013; Tschardt et al. 2014). In a recent study, KPMG (2012) found that the net benefit of cocoa certification in Côte d'Ivoire was on average US\$114 per ton produced between years 1–6 (based on a mean local premium paid for the main three certification schemes, namely Fair Trade, Rainforest Alliance and

UTZ Certified). In Ghana, the net benefit of certification was on average US\$ 382 per ton produced between years 1–6. These estimations are based on rather optimistic yield improvements of 89 % in Ghana and of 101 % in Côte d'Ivoire within 3 years of implementing good practice guidelines and complying with criteria of these eco-labels. These authors suggest that the net benefit would drop down to US\$ 84 (Côte d'Ivoire) and US\$ 38 (Ghana) per ton produced without any productivity increase. Recently, Gockowski et al. (2013) calculated that in Ghana with a premium of 72 GH¢ per ton (around US\$ 40 per ton at the 2013 exchange rate), the profitability of Rainforest Alliance certified cocoa agroforestry systems was less profitable than an intensive monoculture (assumed to produce 20 % more than a well managed cocoa agroforest). In this special issue, Asare et al. (2014) calculate that the on-farm economic benefits of cocoa agroforestry systems in Ghana (including sales of cocoa and timber after 20 years) are not sufficiently attractive to farmers and that a premium of US\$200 per ton for Rainforest Alliance certified cocoa beans, was not substantial enough to compensate for the loss of cocoa productivity in comparison to full sun, intensive cocoa cultivation (again assuming 20 % higher productivity). These authors state that additional revenues provided by the premium cocoa price combined with payment for carbon sequestration (based on a mean carbon sequestration of 155 CO₂ equivalent per ha and at US\$2.05 per ton CO_{2e}) would increase farmers' revenues equivalent to those of full sun cocoa. They conclude that an additional payment for off-farm environmental and ecosystem services at a rate of US\$250 per ha would make agroforestry management attractive enough to stimulate adoption by farmers as part of a biological corridor scheme. Other forms of certification (such as organic) have been shown to result in higher crop prices to farmers while also providing incentives for the maintenance of a permanent tree shade canopy in the cultivation of cocoa and bananas (Hinojosa et al. 2003; Schroth et al. 2014). These recent studies highlight the need for better assessing the long-term effects of implementing good practices, including agroforestry, developed by eco-certification schemes across a wide range of ecological and socio-economical contexts as identified recently in a workshop on cocoa certification in Zurich (ICCO 2014b). This is the sort of issue appropriate to the 'research in development' paradigm

for agroforestry that uses planned comparisons embedded within development projects to understand the adoptability of agroforestry options across large scaling domains and the need for local adaptation (Coe et al. 2014).

The push for full sun intensification

Given a context in which cocoa cultivation has been associated with forest conversion, there is an on-going debate over "land sharing" versus "land sparing" strategies. Best practices, including agroforestry, promoted by eco-certification schemes, have been identified as land sparing in relation to extensive cocoa cultivation (Gockowski et al. 2013), but the cocoa industry mostly advocates farmers adopting intensive, full sun cocoa that they assume requires even less land to achieve the same cocoa production. This management strategy relies on the results of only a few studies in the predominant cocoa producing regions of the world: West Africa and America. In West Africa, only two published studies were found documenting the beneficial effect of removing shade for achieving higher yield. In Ghana, Ahenkorah et al. (1987) reported that the yield of cocoa grown under a moderate level of shade (with an initial density of 67 trees ha⁻¹ reduced to 34 trees ha⁻¹ after 12 years) and fertilizers was only 78 % of that of the full-sun system with the same fertilization, while under a heavy level of shade (with an initial density of 132 trees ha⁻¹ reduced to 68 trees ha⁻¹ after 12 years) the yield was only 50 % of that of the full-sun system. However, this study was conducted under the shade of only one tree species, *Terminalia ivorensis*, a fast-growing pioneer species of West Africa. Furthermore, the study was terminated after 20 years, because the production started declining with the senescence of cocoa trees after 18 years. It is not known if similar results would have been obtained over the next 20 years if cocoa had been replanted and very little research has been conducted on the replanting and rehabilitation of intensified perennial systems (Gockowski et al. 2013). In Cote d'Ivoire, Lachenaud and Mossu (1985) reported that flowering intensity and harvest of healthy pods were respectively 2.18 and 2.47 times greater in full sun than under the shade provided by about 50 trees ha⁻¹ composed of *Terminalia superba*, *Ficus* sp., *Ricinodendron heudelotii*, and *Pycnanthus angolensis*.

However, data were recorded only for 42 months and the trial included only one cocoa hybrid (UF 676 × UPA 402). In Brazil, Johns (1999) reported that yield almost doubled (from 900 to 1,700 kg ha⁻¹ of cocoa beans) with the total removal of the shade trees and use of fertilizers on a series of cocoa farms monitored by researchers of CEPLAC in the cocoa producing region of Bahia during the period 1964–1974. However, the author pointed out that this intensification package was not widely adopted by farmers, who preferred a lower-risk management approach, with occasional use of fertilizers and agrochemicals and the maintenance of shade trees, recognized for their valuable role in limiting ecological risks such as drought and outbreaks of pests and diseases. Although informative, these studies were conducted 20 to 30 years ago and hence may not be relevant to recently improved cocoa germplasm. Over the last 20 years, an overwhelming majority of cocoa genetic trials on yield, resistance to pests and diseases, and response to fertilizer regimes have been conducted exclusively in full sun without any shade treatment. There is clearly a need for initiating a selection program for cocoa genotypes in the context of agroforestry management. In the meanwhile, the technical packages composed of improved hybrid material and high inputs, recommended by extension services in West Africa and to a large extent in other producing regions, have not been widely adopted by farmers, presumably because of lack of access to improved material, the high cost of inputs and underdeveloped rural credit schemes (Gockowski and Sonwa 2011). According to various researchers (Ruf 2011, 2013; Gockowski et al. 2013; Gockowski and Sonwa 2011), less than 30 % of the cocoa plantations of West Africa have been planted with improved cocoa material over the last 30 years and most farmers do not use any fertilizer or, at best, occasionally apply it when cocoa prices are high. Similar management practices have been reported for cocoa cultivation in Central America (Somarriba 2013). It is well known that the soil fertility of cocoa farms established on forest land declines rapidly in full sun, without fertilizer addition, down to levels that result in the collapse of cocoa cultivation within less than 20 years. Furthermore, inorganic fertilizers are efficient in providing nutrients to cocoa plants, but do not improve soil physical properties such as structure and porosity, soil microbial activity or organic matter

content that are key to maintain soil fertility and nutrient cycling. A key role of shade trees is their contribution to soil organic matter and health (Anim-Kwapong and Osei-Bonsu 2009; Barrios et al. 2012).

Agroforestry options for a climate-smart intensification

The multifunctional role of shade trees for farmers' livelihoods and the conservation of natural resources (particularly biodiversity) has been established, highlighting how shade trees in cocoa agroforestry systems enhance functional biodiversity, carbon sequestration, soil fertility, drought resistance and, weed and biological pest control (Clough et al. 2009; Tscharnke et al. 2011; Vandermeer 2011; Somarriba et al. 2012; Deheuvels et al. 2014). This suggests a need for more comprehensive assessment of the long-term effects of shade removal on cocoa yield over a wide range of contexts, in terms of both socio-economic and ecological conditions (Coe et al. 2014).

Cocoa plantations are often predominant in the landscapes of producing countries as exemplified by the Southern regions of Ghana and Cote d'Ivoire or the Northern part of the Island of Sulawesi, Indonesia. This creates a need for a landscape approach to address issues around how tree cover transitions affect environmental services linked to cocoa cultivation (Jackson et al. 2013). Farmers also value shade trees because of their contribution to a range of ecosystem services (Smith Dumont et al. 2014; Cerdán et al. 2012). Often, cocoa extension services promote only a few fast growing or timber producing tree species for growing with cocoa ignoring the wider role of shade trees for livelihoods and the environment (Ruf 2011; Obiri et al. 2007; Ofori-Bah and Asafu-Adjaye 2011; Gockowski and Sonwa 2011; Somarriba and Beer 2011; Somarriba et al. 2014). There is much scope for promoting tree diversity through use of a range of species according to their suitability to match ecological niches, livelihood requirements of farmers and provide a range of ecosystem services such as crop productivity, production diversification, climate adaptation, pest and disease suppression, pollination, soil fertility, water yield and carbon sequestration; and, thereby, sustain cocoa yield. As reported in this present issue by Smith Dumont et al. (2014), Cerda et al. (2014) and Deheuvels et al. (2014), farmers in

West Africa and Latin America overwhelmingly want to have more trees on their farms to sustain their cocoa production, diversify their revenues, improve their livelihood and adapt to climate change. Many farmers are particularly aware of the buffering effects of shade trees against drought and heat stress experienced by cocoa in the dry season. Despite the massive deforestation of the last decades, many forest tree species, including some of high conservation value, are maintained by farmers in cocoa fields, albeit at low frequencies, despite tree use and land-tenure regulations that are not always conducive for them to do so (Smith Dumont et al. 2014).

A key reason for retaining shade trees in smallholders' systems is the reduction of risk, not only with respect to drought and heat, but also price volatility. As stated by Gockowski et al. (2010): “with a shaded system, when prices fall or illness strikes, the farmer can reduce labor input or use of chemicals, without seriously affecting the future productive potential of the cocoa stock. Producers with full sun systems facing pressure from capsids and mistletoe do not have this option. If they do not spray, then their investment will be lost”.

This special issue demonstrates that there is room for improvement in terms of increasing cocoa yield, while preserving the role of shade trees in providing a wide range of environmental services and products. For this, innovative practices have to be developed and adopted by farmers, particularly with respect to shade regulation; including appropriate tree spacing and tree pruning at critical times in the production cycle (i.e. reducing shade at the time of flowering or during wet conditions to reduce the incidence of fungal diseases) or combining tree species with complementary leaf phenology along the production cycle. There is also scope to develop integrated management of pests and diseases that include use of shade tree species that provide functional biodiversity (biological control through maintaining populations of natural enemies, and pollination) in cocoa fields and use of non-host tree species as barriers to the spread of pests and diseases from one contiguous cocoa field to another, as in the case of the cocoa swollen shoot virus in West Africa. Selection of shade trees should equally not be limited to only a few native species. There is a need to develop agroforestry practices that maintain or enhance a diverse tree canopy combining local species for enhancing functional diversity with tree species,

local or exotic, with more specific functions such as legumes for soil fertility enhancement and trees with high timber or carbon sequestration values. The selection of tree species and combinations is likely to be most effective where farmers participate so that their goals and aspirations are taken into account, and their local agroforestry knowledge is incorporated into the design and management of the system (Anglaere et al. 2011; Cerdán et al. 2012).

By improving yield, resilience to climate change and provision of environmental services while minimizing dis-services of cocoa systems, it might be possible to provide sustainable ways to stabilize cocoa production within today's producing regions, particularly West and Central Africa, thereby avoiding the boom and bust cycles typical of cocoa cultivation over the last centuries (Ruf 2011), and perhaps preventing the deforestation of the humid forest in the Congo basin where cocoa cultivation is rapidly expanding (G. Savio, personal communication).

How this special issue contributes to development of cocoa agroforestry

The 13 articles constituting this special issue on cocoa agroforestry were chosen to address the current issues in cocoa agroforestry that we have outlined in this editorial. Four studies illustrate the role of trees in improving the livelihoods of rural families through production of timber, fruits, fuelwood and medicine, and in reducing risk with respect to cocoa price volatility (Cerdeira et al. 2014; Jagoret et al. 2014; Somarriba et al. 2014; Sonwa et al. 2014). Three further articles illustrate how risk-averse farmers use shade trees as a long term strategy to avoid vulnerability of their cocoa systems against insect and disease outbreaks and climate change, particularly water and heat stresses (Gyau et al. 2014; Jagoret et al. 2014; Smith Dumont et al. 2014). The relationships between management intensity of cocoa and the conservation of biodiversity are explored by Tadu et al. (2014) and Deheuvels et al. (2014). The provision of ecosystem services by cocoa agroforestry is documented by Vebrova et al. (2014) and the role of organic certification in promoting carbon sequestration and tree diversity in cocoa systems is explored by Jacobi et al. (2014). The relationships between cocoa yield, income and carbon sequestration in traditional cocoa

agroforests in Cameroun are explored by Magne et al. (2014); while the use of cocoa agroforestry systems as biological corridors to improve forest connectivity is assessed by Asare et al. (2014). Pédelahore (2014) illustrates how farmers' strategies in terms of capital accumulation affect the degree of management intensification on their cocoa systems.

Acknowledgments In the name of the authors of this special issue on cocoa agroforestry, we thank all the anonymous reviewers for their valuable inputs. Funding support was provided by CATIE, CIRAD, ICRAF and the Forest Trees and Agroforestry research programme of the CGIAR.

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