Ecological Economics 140 (2017) 136–145

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Shaded Coffee and Cocoa – Double Dividend for Biodiversity and Small-scale Farmers

Jezeer Rosalien E. [a,*], Verweij Pita A. [a], Santos Maria J. [c], Boot René G.A. [b,d]

[a] Group Energy and Resources, Copernicus Institute of Sustainable Development, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands
[b] Tropenbos International, Lawickse Allee 11, 6701 AN Wageningen, The Netherlands
[c] Group Environmental Sciences, Copernicus Institute of Sustainable Development, Utrecht University, Heidelberglaan 2, 3572TC Utrecht, The Netherlands
[d] Group Ecology & Biodiversity, Institute of Environmental Biology, Utrecht University, Padualaan 8, 3584 CH Utrecht, The Netherlands

ARTICLE INFO

Article history:
Received 18 August 2015
Received in revised form 5 October 2016
Accepted 23 April 2017
Available online 10 May 2017

ABSTRACT

This paper compares financial and biodiversity performance of small-scale shaded coffee and cocoa plantations versus intensified conventional ones. We conduct a meta-analysis including 23 studies on coffee and cocoa plantations over a 26 year period. Our results show that, contrary to common perceptions, profitability and cost-efficiency are higher for small-scale shaded systems. Despite the lower yields for shaded systems, the lower costs per area and higher price per kilogram of coffee or cocoa causes shaded systems to perform better financially. This finding shows that the traditional indicator 'yield' is an inaccurate measure of financial performance when studying diversified systems, and that the more detailed indicators as net revenue or benefit-cost ratio should be used instead. Few studies specifically reported on the relationship between biodiversity and financial performance, providing divergent results, yet various papers showed a promising optimum relationship for intermediate levels of shade. Because shaded systems are known to correlate positively with biodiversity, we postulate that they can offer competitive business opportunities for small-scale farmers, while also contributing to biodiversity conservation. Still, there is a pressing need for multidisciplinary studies to quantify financial and biodiversity performance simultaneously, and to identify opportunities for scaling up shaded systems.

Contents

* Corresponding author at: Section Energy & Resources, Copernicus Institute of Sustainable Development, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands.
E-mail addresses: R.E.Jezeer@uu.nl (R.E. Jezeer), P.A.Verweij@uu.nl (P.A. Verweij), M.J.FerreiraDosSantos@uu.nl (M.J. Santos), Rene.boot@tropenbos.org (R.G.A. Boot).

http://dx.doi.org/10.1016/j.ecolecon.2017.04.019
0921-8009/

1. Introduction

Tropical agroforestry is seen as a promising approach to reconcile biodiversity conservation and local development (Atangana et al., 2014; Perfecto et al., 2005; Philpott et al., 2007; Schroth et al., 2004; Waldron et al., 2012). Together, coffee and cocoa represent an important component of the international commodity trade volume (Tscharntke et al., 2011), providing income for over 30 million smallholders, predominantly in developing countries (Ovalle-Rivera et al., 2015; Ponte, 2002). Traditionally, coffee and cocoa crops are grown under a dense canopy of various indigenous shade tree species, and these crops form a considerable amount of the world's area under agroforestry management (O'Brien et al., 2003; Perfecto and Vandermeer, 2008; Tscharntke et al., 2011). However, there is a strong tendency worldwide to intensify these traditional shaded systems by reducing or eliminating shade trees, planting higher densities of new coffee and cocoa varieties, and using agrochemical inputs. All these efforts are aimed at increasing production and short-term income (Clough et al., 2011; Juhrbandt, 2010; Rice and Greenberg, 2000; Siebert, 2002). Consequently, worldwide the largest share of coffee and cocoa area is currently being managed without shade, and only less than a quarter of such area with multi-layered, diversified shade (Jha et al., 2014). Thus, there are a variety of coffee and cocoa management systems along a gradient of intensification, ranging from low-input rustic agroforestry plantations with high levels of shade to high-input monoculture plantations without shade (Moguel and Toledo, 1999; Perfecto et al., 2005). Due to this variety, the coffee and cocoa agroecosystems are suitable as model systems to study the impact of agricultural intensification. Although there are sufficient data on the ecological importance of coffee and cocoa agroforestry systems for biodiversity conservation (De Beenhouwer et al., 2013), evidence of the trade-offs between biodiversity performance and socio-economic benefits or their potential double dividend is lacking, as there are only few multidisciplinary studies that quantify both.

Biodiversity benefits associated with shaded coffee and cocoa practices are well researched. There is ample evidence that these systems have a considerable potential to conserve biodiversity, as complex agroforestry systems have been reported to sustain species richness equivalent to >60% of that of natural forests (Bhagwat et al., 2008; Harvey et al., 2006; Moguel and Toledo, 1999; Rice and Greenberg, 2000). However, there is no consensus on how productive and profitable these systems are in comparison to intensive, conventional management systems (Clough et al., 2011; Steffan-Dewenter et al., 2007). Some studies state that agroforestry, representing a form of extensive land use, cannot meet the growing demand for food; therefore, they advocate agricultural intensification to minimize the conversion of natural habitats (Chandler et al., 2013; Gabriel et al., 2013; Green et al., 2005; Phalan et al., 2011). Other studies, however, suggest that coffee and cocoa systems can be designed to optimize both biodiversity and economic benefits without adding pressure on natural habitats (Clough et al., 2011; Scherr and McNeely, 2008; Tscharntke et al., 2011).

Considering the economic and ecological importance of coffee and cocoa, it is important to gain more insight into the financial and biodiversity benefits, as well as into the opportunities to reconcile these. In this paper we synthesize currently known trade-offs between biodiversity performance and financial performance of small-scale shaded plantations versus conventional coffee and cocoa plantations. We present the results of a meta-analysis including data of 23 different studies on shaded cocoa and coffee systems. The central question addressed is if the financial and biodiversity performances of small-scale shaded coffee and cocoa systems are similar or higher than those of conventional systems. To provide an answer to this question, we developed a meta-analytic framework computing a comprehensive database by calculating and including information on financial, economic and biodiversity performance indicators for a wide range of small-scale shaded coffee and cocoa systems. This analysis enabled us to make a better informed synthesis of the potential double benefits of shaded coffee and cocoa systems. We emphasized the financial performance as there is little consensus on the financial benefits, even though profitability is expected to be an important determinant for the choices of smallholder farmers (Pannell, 1999). In this paper, we discuss both the ecological and financial benefits of shaded coffee and cocoa cultivation as a function of shade management, and we provide recommendations for further research to enhance these benefits.

First, we compare shaded systems with conventional ones according to the results of the financial performance analysis. Second, we briefly discuss the different coffee and cocoa management systems in relation to biodiversity, with an emphasis on shade level and management intensity. Third, a systematic literature review is used to link biodiversity and financial performance of small-scale shaded coffee and cocoa systems. Finally, we discuss the implications of our findings for environmental policy and research.

2. Methodology

2.1. Literature Search and Data Collection

We systematically searched for scientific and grey literature using the following search terms in Google Scholar: “Biodiversity AND shade AND agroforestry AND (tropics OR tropical) AND (product OR productivity OR profit OR profitability OR yield OR financial OR finance)”, of which the first 1000 results were included. Studies were selected if they included (i) coffee or cocoa systems; (ii) an intensified conventional system and a shaded system, and there is mentioning of difference in shade between the two systems in the paper; (iii) quantitative information on yield (kg ha^{-1}) and/or costs and benefits (monetary currency), in terms of e.g. input costs, net revenue, labour time and costs, or Benefit-Cost Ratios (BCR); and (iv) quantitative information on biodiversity performance in terms of species richness. These criteria were applied to both scientific and grey literature encountered in the first thousand Google Scholar results. Besides studies that included a direct indicator of biodiversity performance such as species richness, studies including proxy variables known for their correlation with biodiversity such as canopy closure and shade tree density (Bhagwat et al., 2008; Harvey et al., 2008) were also selected. Only papers including shade provided by trees were included, avoiding papers describing artificial shade, for example shade provided by cloth. For financial performance, indicators such as productivity and costs were used. Besides systems referred to in the encountered literature as shaded or agroforestry systems, a broader range of study systems was incorporated as 'shaded systems', including organic, certified or low-input systems, only if there was mentioning of a certain level of shade management in the system.

Furthermore, systems referred to as sun-grown, unshaded monoculture or uncertified were included as 'conventional systems' representing an intensified alternative system. The complete list of selected studies and extracted data is provided in the electronic supplementary material, Table A.1. Data were extracted from articles, integrated into one database and converted to the same units of measurement: 1 ha was used as the unit for surface area, 1 year as unit for time, and US dollar as currency. Benefit-Cost Ratio (BCR) and net revenue (US$ ha^{-1}) are used as main indicators of financial performance, as they provide insight into the dynamics between costs and benefits and the total profit per surface area. There were insufficient data on variables such as discount rate, plantation age and labour time and costs to take these explicitly into account and to analyse their effects separately. Coffee and cocoa yields are expressed in dry weight. If necessary, coffee fresh weight was converted to dry weight using a 4.6:1 ratio (Hicks, 2002). All cocoa studies presented dry weight figures. In addition, data on trees per hectare (trees ha^{-1}), costs per hectare (US$ ha^{-1}), gross revenue per hectare (US$ ha^{-1}) and net revenue per hectare (US$ ha^{-1}) were calculated when possible and included in the database. Shade tree density categories were defined according to number of shade trees per hectare (low < 40, medium 41–100 and high > 100 trees). Shade quality was identified according to shade tree density and the description of the system in the article.

2.2. Description of Dataset and Analysis

A total of 23 articles are included in this review; they were published between 1988 and 2014 and matched the inclusion criteria mentioned above. All selected articles contain data of a single conventional system and one or several shaded systems. Although some articles lacked a detailed description of shade tree density and species richness, it was clear that the shaded systems included in this analysis showed a large range in shade complexity and therefore quality. The shaded systems ranged from highly diverse shaded systems, often referred to as rustic systems (as characterized by Moguel and Toledo, 1999), to shaded monocultures systems where shade is provided by a single species. Each shaded system is paired to the unshaded conventional system in the article. Consequently, when one article describes more than one shaded case, the data used in the analysis for the conventional counterpart system are replicas. The basic units of analysis in the database were these paired cases, allowing for a comparison between a shaded system and a conventional system. Indicator analysis predominantly focused on paired cases within a study, expressed as a relative difference between the shaded and conventional system within one study. Most studies used field data, although some studies based their modelling on empirical data.

A subset of five articles contained continuous data and was therefore reviewed separately. These articles contained data on both financial performance and biodiversity performance; they originated from different regions in Africa (2), Asia (1) and Latin America (2) and four of these concerned cocoa. The remaining 18 articles contained categorical data, allowing for quantitative analysis of financial performance by means of a meta-analysis. A total of 31 categorical paired cases were identified and numbered (Table A.1), and these numbers are used to refer to the cases. Of these categorical data, three articles reported explicitly on biodiversity, resulting in a total of six cases that included data on biodiversity and financial performance. Table 1 presents an overview of the categorical dataset and the most important variables with corresponding units of analysis. A subset was made of all 20 cases that included BCR information, thus also forming a subset of the other indicators. Although we do not imply that coffee and cocoa systems are identical, we assume that the great similarities between the two systems (Beer et al., 1998; Tscharntke et al., 2012) allow for combined analysis, especially since this analysis involves pair-wise comparisons. Our data shows no indication that we should question this assumption, but differences in results between the two crops are addressed when necessary.

Table 1
Selected articles as a result from the literature search, with corresponding number of cases per indicator. BCR = Benefit-Cost Ratio.

Total dataset		# of articles 18	# of cases 31	# cases BCR-subset
BCR	Ratio	11	20	20
Yield	kg ha^{-1}	14	25	15
Coffee shrub/cocoa tree density	shrubs ha^{-1}, trees ha^{-1}	10	14	9
Productivity per shrub/tree	kg $shrub^{-1}$, kg $tree^{-1}$	7	10	5
Costs	US$ ha^{-1}	8	15	15
Coffee price	US$ kg^{-1}	5	8	8
Gross revenue	US$ ha^{-1}	4	11	8
Net revenue	US$ ha^{-1}	10	19	15
Biodiversity	Species diversity & abundance	3	6	4

A total of 26 of the selected cases provide data from coffee plantations, compared to 5 cases of cocoa plantations. Of all categorical articles, 5 contained data from African plantations and 13 from Latin American plantations (Fig. 1). Differences in mean indicator value (BCR, yield, tree density, productivity per tree, costs, product price and net revenue) between shaded and conventional systems were tested by conducting one-sided, paired sample *t*-tests (R, version 3.0.2, R Core Team 2014). This analysis allowed for comparison of means between groups while taking the paired cases into account and *p*-values, t-test values and degrees of freedom (df) are reported. One-way ANOVA tests were conducted to test for differences in variance in indicator value (BCR, yield, and net revenue) among the characterized low, medium and high shade tree densities (A.1), for which *p*-values, F-values and degrees of freedom (df) are reported.

3. Results

3.1. Financial Performance

In this section, we analyse the financial performance of conventional and shaded coffee and cocoa systems, predominantly by presenting the results of the analysis of the BCR-subset. First, we present the results of the analysis of BCR and net revenue as main indicators of financial performance. Subsequently, the results regarding yield, cost and product price are presented and analysed in relation to BCR and net revenue, providing more insight into the underlying components of the financial performance of coffee and cocoa systems. An overview of the results is presented in Fig. 2.

3.1.1. Net Revenue and BCR

Our analysis showed that shaded systems were more cost-effective (BCR) and profitable (net revenue) than conventional systems, indicating a better financial performance. Data showed a trend ($p < 0.10$; $t = 1.47$; df = 19) that average BCR of shaded systems 1.66 (± 0.22; $n = 20$) was higher than that of conventional systems 1.44 (± 0.16; $n = 11$; Fig. 2). Additionally, the average net return of shaded systems in the subset was significantly higher by 23% ($p < 0.05$; $t = 2.31$; df = 14), showing a higher profit per hectare for farmers with shade trees planted between their coffee and cocoa plants. Despite differences in net revenue and BCR, the majority of cases were profitable; in other words, they had a BCR higher than 1.0 and gross revenues that were higher than the costs. No significant difference in net revenue ($p > 0.05$; F = 0.72; df = 10), yield

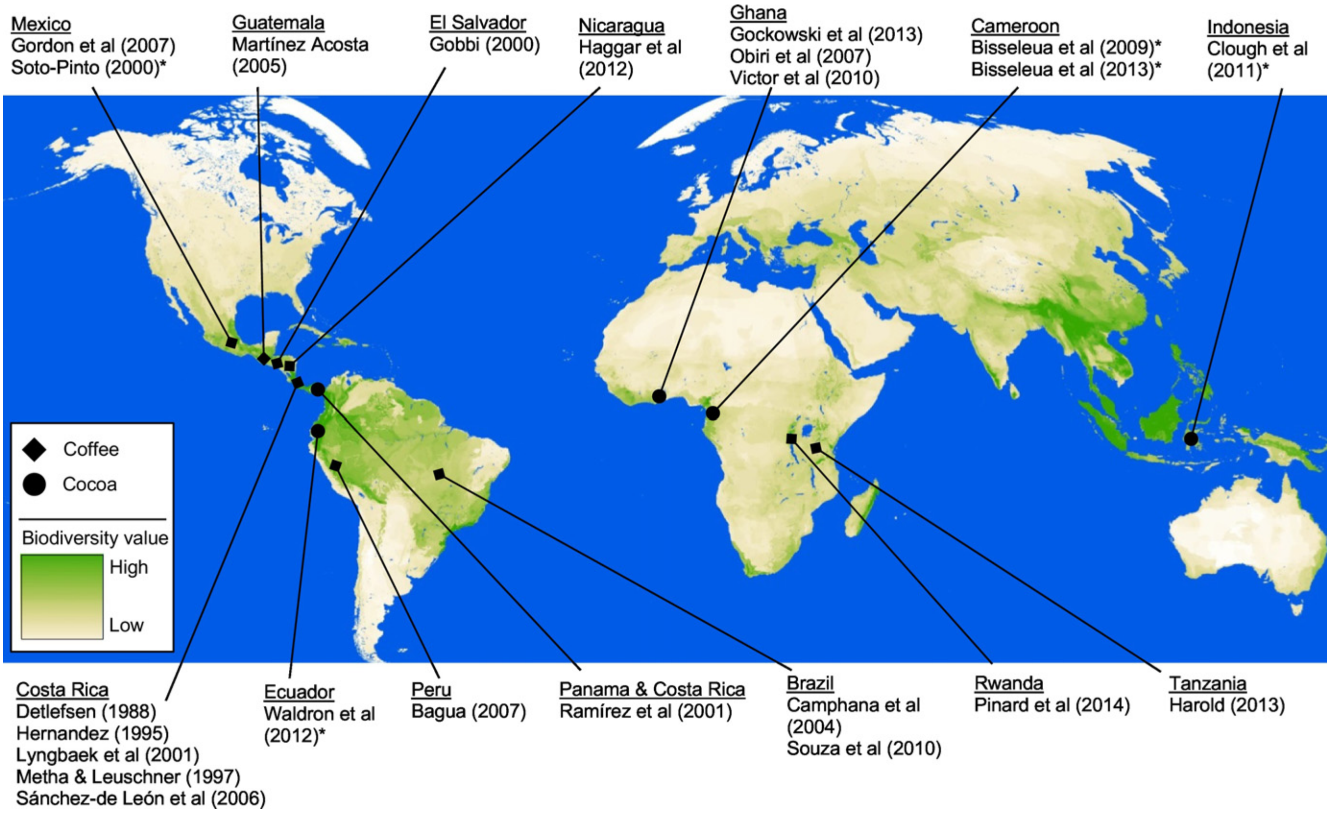
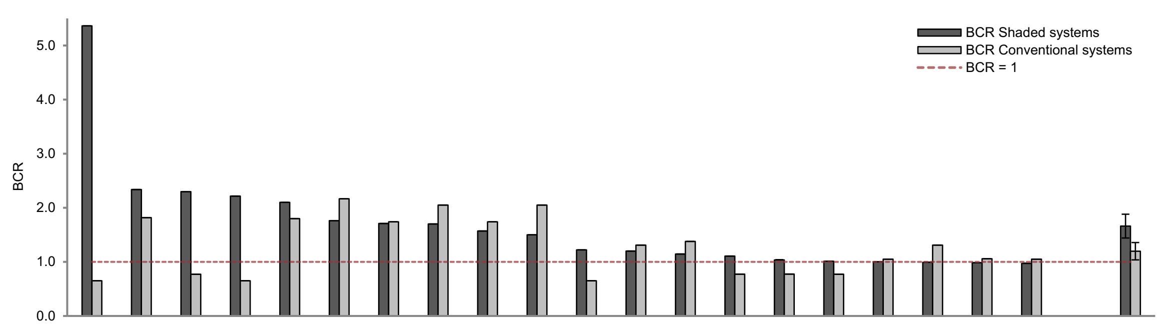


Fig. 1. Geographical locations of the study, plotted on a map showing the worlds' biodiversity hotspots from high (green) to low (white). *Indicates articles with continuous data. For full list of references, see A.1. Map derived from: http://static1.squarespace.com.

($p > 0.05$; F = 0.12; df = 17) or BCR ($p > 0.05$; F = 1.98; df = 11) was found across different levels of shading (low, medium or high shade tree density).

3.1.2. Yield

For 25 cases data were reported on yield, 15 of which also presented data on BCR (Table A.1). Productivity per hectare for shaded systems decreased 26% compared to conventional systems ($p < 0.001$; $t = -4.37$; df = 24). This difference in yield is reflected by the higher coffee and cocoa tree density and higher per plant productivity for conventional systems. No significant difference in yield was found among low, medium and high shade tree densities ($p > 0.05$; F = 0.12; df = 17). The average tree density was 32% higher for conventional systems, a difference which was significant ($p < 0.001$; $t = -2.88$; df = 13).



Case #	10	29	13	12	18	17	23*	21	24*	20	11	9*	26*	15	16	14	30	8*	19	31	Average	SE	n
Yield difference (%)	-28%	-39%	-41%	-13%	-44%			-45%		-35%	-51%	-22%	-15%	-21%	59%	22%		-80%	-22%		-25%***	8%	15
Trees ha^{-1} difference (%)		-23%			-34%	8%						0%	-36%				0%	0%	-8%	0%	-10%*	5%	9
Yield tree^{-1} difference (%)		-22%			-6%							-22%	32%					-80%			-19%**	18%	5
Costs difference (%)	-80%	-67%	-51%	-47%		-26%	34%	-65%	37%	-5%	-63%		82%	-38%	60%	23%			5%		-13%	13%	12
Price kg^{-1} difference (%)	0%	0%	64%			34%				0%				-2%	18%	20%			21%		17%*	8%	8
Gross revenue difference (%)		-39%	-9%			30%	55%		46%					-26%	84%	40%					23%	15%	8
Net revenue difference (%)	68%	-5%	45%	81%		-39%	64%		50%		-30%	-17%	51%	-11%	115%	62%		-82%	-2%		23%**	14%	15

Fig. 2. BCR (Y-axis) of shaded coffee and cocoa systems compared to conventional systems (X-axis, $n = 20$). Dotted line represents break-even point of BCR = 1.0, where costs and benefits are equal. Cocoa cases are indicated with (*). In the connected table, differences in yield (kg ha^{-1}), coffee tree density (trees/ha), productivity per tree (kg tree^{-1}), costs (US$ ha^{-1}), price received per product (US$ kg^{-1}), gross revenues (US$ ha^{-1}) and net revenues (US$ ha^{-1}) are presented in percentages. Red cells indicate a negative difference for shaded systems compared to conventional systems, with all differences ≤50% are marked in darker red, and green cells represent a positive difference, where darker green cells indicate a positive difference of >50%. SE and n of average values of all variables are presented. *** indicates a significant level of <0.01, ** of 0.05 and * of 0.10 derived from one-tailed t-tests.

Furthermore, data showed a trend towards higher average productivity for conventional systems per coffee shrub of cocoa tree by 18% ($p < 0.10$; $t = 1.38$; df = 9).

To provide more insight into the underlying components of cost-effectiveness and profitability, it is important to examine the data of the 15 cases included in the BCR-subset that reported on productivity. Overall, yield per hectare was 25% lower for the shaded systems than for the conventional systems ($p < 0.01$; $t = -3.06$; df = 14), ranging from +59% to −79%. Of the 15 cases, 13 showed higher productivity per hectare for shaded systems in comparison to conventional systems, leaving two cases (nos. 14 and 16) with a higher yield for the shaded systems (22% and 59%, respectively). All shaded cocoa systems were less productive per hectare than their conventional counterparts, as yields were between 15% and 80% ($n = 3$) lower for shaded systems. Comparable with the total dataset, the differences in the productivity of this subset can be explained by trend in a 10% lower coffee and cocoa tree density in the shaded systems ($p < 0.10$; $t = -1.60$; df = 8) combined with a non-significant difference of 19% lower productivity per tree ($p > 0.10$; $t = 2.8$; df = 5).

3.1.3. Costs

A total of 15 cases, all within the BCR-subset, presented data on costs. On average, costs per hectare associated with shaded systems were 13.2% lower than for conventional systems, but this difference was not significant ($p > 0.10$; $t = -1.03$; df = 14). In these cost analyses, the level of detail differed between cases, as did the components included, such as labour costs, input costs, land prices and certification costs.

3.1.4. Product Price

Besides productivity, an important determinant for net income is the price farmers receive per unit of product (expressed as US dollar per kilogram: US$ kg^{-1}). Although most cases lacked data on product price, 10 coffee cases presented price per kilogram of coffee beans; four of these cases adopted the same coffee prices for the two different systems, resulting in identical prices for conventionally and shade-grown coffee. The remaining six cases presented prices per kilogram of certified coffee beans, resulting in a price premium for shade-grown coffee in these studies. With the exception of one case in which the coffee price was 2% lower for shaded systems (no. 15), all prices were higher for shaded systems, ranging from an 18–64% increase in dollar per kilogram. In these 6 cases there was a trend towards higher average prices for shaded coffee and cocoa by 26% per kilogram, than the price received by conventional farmers ($p < 0.10$; $t = 1.91$; df = 5).

3.2. Biodiversity Performance and Financial Performance

One of the main characteristics of intensification is the reduction or elimination of shade trees resulting in monoculture plantations without shade. Since the level of shade provided by shade trees is relatively easy to quantify and its relationship with biodiversity is well researched, shade is often used as a proxy indicator of biodiversity. Similarly, productivity in terms of yield of the main cash crop is often used as an indicator for financial performance. Consequently, cases that included these proxy indicators for biodiversity and financial performance are also presented here.

3.2.1. Shade, Yield and Income

All five continuous data studies included in this review explicitly studied the relationship between shade trees and productivity in terms of coffee or cocoa yield and/or income, yielding contrasting results (Table 2). Clough et al. (2011) found a negative relationship for cocoa production as yield decreased with an increasing percentage of shade. However, other studies show an optimum relationship (Bisseleua et al., 2009; Soto-Pinto et al., 2000; Waldron et al., 2012) for intermediate levels of shade. Two of these studies explicitly studied revenues in terms of income of systems with different levels of shade, again with contrasting results similar to the shade-yield relationships. Bisseleua et al. (2013) found a negative linear relationship between the level of shade and income, as income decreased with an increasing percentage of shade. Data presented by Waldron et al. (2012) indicate an optimum for intermediate levels of shade in relation to income for smallholder farmers.

3.2.2. Species Richness, Yield and Income

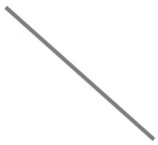
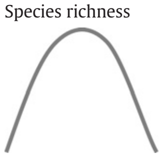
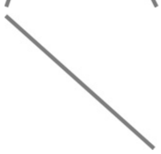
Studies analysing the relationship between species richness and yield and/or income show divergent results. Bisseleua et al. (2013) found that there was a negative relationship between the diversity of native shade trees in cocoa plantations and productivity, although the correlation was relatively weak. This is in contrast to another study by Bisseleua et al. (2009), which reported an optimum relationship between species richness and yield as well as between species richness and income. This study observed the highest net income with intermediate ant species richness. Clough et al. (2011) found no relationship between species richness and yield. Furthermore, two papers containing categorical data included data on both species richness and BCR and net revenue (Table A.2.). Gordon et al. (2007; nos. 10–12) showed that bird diversity was between 120 and 306% higher in three shaded coffee systems ranging in complexity, whilst BCR and net revenue were also significantly higher for all three shaded systems despite an overall decline in yield. The same trend was found on coffee plantations in Nicaragua studies by Haggar et al. (2012).

4. Discussion

4.1. Management Characteristics and Biodiversity

Since there is a broad variety in coffee and cocoa management systems, these systems can be used to study the effect of intensification on both biodiversity and financial performance. Differences with respect to for example shade trees, input of agrochemicals, coffee and cocoa varieties and tree density can all be located along this gradient of intensification. Numerous studies investigated the relationship between the intensity of crop management and the biodiversity performance of coffee and cocoa systems, in order to determine the potential of agroforestry systems to conserve biodiversity, as well as the circumstances such as the quality of the matrix and management practices involved. Some studies reported a decline in biodiversity when coffee or cacao management intensifies (e.g. Faria et al., 2007; Gardner et al., 2009), whereas other studies did not find such an overall effect (e.g. Steffan-Dewenter et al., 2007; Gordon et al., 2007). Though the conservation of biodiversity is influenced by many different factors and outcomes are divergent, there are some clear messages that can be drawn from the literature. Overall, there is substantial evidence that naturally shaded systems have a great potential to conserve biodiversity (Bhagwat et al., 2008; Harvey et al., 2008). Although different taxa respond differently to habitat modification through intensification of both of coffee and cocoa agroecosystems (Perfecto et al., 2003; Schroth et al., 2004), it is well known that a reduction of shade quality will have a negative effect on biodiversity conservation potential. Species richness is typically highest in coffee and cocoa systems with high plant diversity, and structurally complex canopies. De Beenhouwer et al. (2013) performed a meta-analysis of 74 studies and concluded that there was a stronger decline in total species richness when comparing agroforestry systems with plantations (−46%) than when comparing forest with agroforestry (−11%), confirming the general idea that both plant and animal diversity in coffee and cocoa agroforests are higher than those of other agricultural land uses, but lower than in the original forest habitat. Species richness is often significantly related to plantation characteristics such as canopy closure, management intensity index, shade tree density and other vegetation characteristics (Clough et al., 2009; Marín et al., 2016; Schroth and Harvey, 2007).

Table 2
Qualitative analyses of biodiversity and financial performance for five studies presenting continuous data. Relationship between biodiversity (x-axis) and financial performance (y-axis) indicators is presented abstracted and when available statistics are included.

Biodiversity performance indicator (x-axis)	Financial performance indicator (y-axis)	
	Yield	Income
Shade		
	Bisseleua et al. (2009) (r2 = 0.41, p = 0.006) Soto-Pinto et al. (2000) (r2 = 0.68; $p < 0.001$) Waldron et al. (2012) (r2 = 0.69)	Waldron et al. (2012) (r2 = 0.57)
	Clough et al. (2011) ($p < 0.05$)	Bisseleua et al. (2013) (0.72 ($p < 0.0001$)
Species richness		
	Bisseleua et al. (2009)	Bisseleua et al. (2009)
	Bisseleua et al. (2013) (r2 = 0.25; $p < 0.05$)	
	Clough et al. (2011)	

Such plantation characteristics are often used as indicators of species richness, both in research and in certification practices. We therefore assume that the shaded systems included in our analyses offer a greater potential to conserve biodiversity than the conventional systems they were paired with. While we did include shade quality in the analysis by categorizing shade tree density (low, medium, high, A.1.), the lack of more detailed case descriptions of shade quality hampered an adequate analysis of its effect on both biodiversity and financial performance. It should be noted that there is a wide range in shade quality reported in the studies included in this analysis, ranging from very low shade tree density values of 12 trees per ha^{-1} (no. 9), to high shade tree densities of 400 trees per ha^{-1} (no. 4; A.1.), and from single to multiple species of trees. We consequently expect large differences in biodiversity performance within the pool of shaded systems. A more detailed and consistent description of shade and shade management practices across studies would help to overcome such shortcomings. Besides quality of shading practices, the same accounts for other management characteristics such as the use of agrochemicals and the quality of the surrounding matrix. Although these variables are known to have important effects on biodiversity, little is known about the effects of these *in situ* and *ex situ* plantation characteristics on the financial performance of these systems, and information on the trade-offs between economic and biodiversity performance is even scarcer.

4.2. Financial Performance

In this study, financial performance was determined with both input and output indicators. First, the results of the analysis on financial performance are discussed in terms of profitability and cost-efficiency. Then, BCR and net revenue are broken down into their separate components to discuss the opportunities and disadvantages associated with shaded systems.

4.2.1. Profitability and Cost-Efficiency

With net revenue and BCR taken as financial performance indicators, shaded systems showed a better financial performance as average net revenue and BCR were higher for cocoa and coffee systems intercropped with shade trees. Interestingly, the highest BCR (5.36) was found in a case describing extensive agroforestry sites (no. 10). This high BCR is not directly related to an improvement in yield, as the yield was 28% lower compared to the conventional reference system. However, the costs associated with the production of coffee (per ha per year) were 80% lower and net revenue was 68% higher (Fig. 2). Coffee prices received per kilogram were assumed for the different systems and, consequently, were identical; therefore, these prices do not explain the difference in financial performance. In practice this means that a premium price as a result of certification could be an opportunity to further increase the cost-efficiency and profitability for these agroforestry cases. Case no. 10 is exceptional as the overall yield only poorly explains its financial performance. Despite higher BCR and net revenue of shaded systems, the yield values for shaded systems were on average 26% lower than for conventional systems. It is therefore interesting to consider the separate components of net revenue and BCR. Indeed, on the one hand shaded systems had lower average costs (13%), while on the other hand they received higher average gross benefits per hectare (23%), which is partly a reflection of the higher average price per kilogram of coffee or cocoa (17%).

4.2.2. Coffee and Cocoa Yield

The lower average yield (−26%) found for shaded systems in comparison to conventional systems is in accordance with the majority of the literature, confirming the negative linear relationship between shade and production of the main cash crop (Foley et al., 2011; Seufert et al., 2012). Even though this is often directly attributed to a decrease in solar radiation (Campanha et al., 2004; Vaast et al., 2006), there are increasing numbers of studies showing that moderate shade levels have little effect on cacao and coffee plant productivity (Perfecto et al., 2005; Soto-Pinto et al., 2000). Other studies found that a shade cover of 23–38% could even have a positive effect on yield, and that yield remained stable at a shade cover between 38 and 48%, but that production was lower when shade cover exceeded 50% (Somarriba and Beer, 2010). This parabolic relationship is confirmed in a study by Bisseleua et al. (2009), who found that yield was positively influenced by a shade cover of 28–47%, that yield remained stable at a shade cover of 49–55%, and that yield decreased at a shade cover of over 60%. In agroforestry systems, coffee and cocoa trees are planted beneath shade trees; however, coffee and cocoa trees are also frequently intercropped with perennials such as banana. van Asten et al. (2011) showed that coffee–banana intercropping is much more beneficial for smallholders than banana or coffee mono-cropping, since the coffee yield was not affected and farmers gained additional income from the bananas, thereby offering a good business opportunity for small-scale farmers. Although banana plants in such a system are expected to provide shade and extra income, the difference in biodiversity conservation value compared to plantations with high quality shading should be taken into consideration.

4.2.3. Yield as an Indicator of Financial Performance

Studies addressing the socio-economic impact of coffee and cocoa agroforestry systems often extract financial performance solely based on the yield of the main cash crop. This is not surprising, as yield is the common denominator of different systems. However, an important finding in this review is the absence of a direct relationship between coffee and cocoa productivity, both per surface area and per tree, and financial performance expressed as BCR and net revenue (Fig. 2). This indicates a more complex relationship than is often assumed between yield and financial performance (Steffan-Dewenter et al., 2007), which questions the use of yield as a direct indicator of financial performance. Nonetheless, the relationship between yield and management characteristics (in this study shade provided by trees) provides important insight into the trade-offs for coffee and cocoa systems. Productivity data are indeed useful to predict financial performance, but results should be interpreted with due caution and in the right context.

4.2.4. Costs

Intensification of coffee and cocoa management systems is associated with an increase in agrochemical input and management intensity, which is expected to be reflected in higher costs, especially since prices of chemical fertilizers have increased over the last decade (ICC, 2014). Put reversely, Hoekstra (1987) described that agroforestry systems have a higher output value at the same resource cost or have the same output value at a lower resource cost when compared to non-agroforestry systems. We found similar results, as costs per hectare were 13.2% lower for shaded systems in comparison to conventional systems, partially explaining the better financial performance of shaded systems. These predicted dynamics are reflected in Gobbi (2000), who demonstrates that capital requirements for organic shaded systems are low and that these requirements increase with reduction in shade cover. Bisseleua et al. (2013) confirms this relationship as they found that higher input in studied cocoa farms does not necessarily result in a higher net return. Besides agro-chemical input, labour is often one of the major costs incurred in plantation management, while type and allocation of labour vary among different management systems. For example, the organic shaded systems in the study of Lyngbæk et al. (2001, no. 19) required more labour than the conventional unshaded systems in this study, mostly because more hours were needed for fertilization and pest control and pruning of the shade trees. However, the lower input costs associated with the organic systems in this study compensated for the increase in labour requirements, resulting eventually in similar costs. Since small-scale farmers often have only limited access to resources and finance, shaded coffee and cocoa systems appear to be an attractive option for this group as shaded systems involve lower costs in the establishment and maintenance of the plantations. Additionally, a distinction between actual incurred costs of hired labour and opportunity costs of family labour in the economic analysis would be useful. Small-scale subsistence farming often relies more on family labour, avoiding costs associated with hired labour, in contrast to larger scale plantations which are often more intensively managed and rely more on hired labour, which comes at additional costs. Further research is therefore recommended on the effects of agrochemicals and environmental conditions on productivity, as well as the relative contribution of family and hired labour to costs incurred.

4.2.5. Coffee/Cocoa Price and Certification

An important determinant of income derived from plantations is the price per kilogram of produced coffee or cocoa received by the farmers. The price of shade-produced coffee or cocoa can be potentially higher due to increased quality and therefore suitability for specialty markets (Muschler, 2001; Vaast et al., 2006) as well as price premiums from environmental certification schemes. In this review, the price received per kilogram of dry coffee or cocoa beans was indeed higher (18%) for farmers growing shaded coffee or cocoa compared to the price received for conventionally grown coffee. This partially explains the observed better financial performance for shaded systems. Price premiums received by small-scale farmers as a result of environmental certification thus seem to play an important role (Lyngbæk et al., 2001) and show potentially better economic prospects for small-scale farming, as the specialty coffee market has increased over the last decade and is expected to keep growing (Jha et al., 2014). Other research however argues that although the price premium can play a role, yields rather than these price premiums are most important for net income of coffee farmers in Mexico (Barham and Weber, 2012). Overall, if farmers are to consider switching from a conventional to a shaded system, the presumed decrease in coffee or cocoa yield needs to be compensated by a price premium, irrespective of the difference in quality of the product. Although coffee prices are in part determined by quality, worldwide coffee and cocoa price fluctuations put farmers in a vulnerable position (Belsky and Siebert, 2003; Ponte, 2002). As shaded systems are more diverse than conventional systems, they are expected to show a lower sensitivity to changes in commodity prices, as income derived from other products can contribute greatly to the income of small-scale farmers (Rice, 2008). Unfortunately, the selected cases had only limited data on the benefits associated with diversification, which made it impossible to include this aspect separately in the quantitative analysis. Still, some cases addressed the benefits of additional income or income stability. An example is provided by Souza et al. (2010, case 29), where income derived from other products adds more than a third to the income derived from coffee (R$1792.00 from coffee and R$701.50 from other products). The same applies to cases 20 and 21, where income from timber and firewood accounts for >70% of the total income derived from shaded coffee plantations. Such additional income can reduce the sensitivity of farmers' livelihoods to fluctuations in commodity prices. This is illustrated by case 10, described by Gordon et al. (2007), who showed that a recent coffee price crash on the international market had a much greater impact on the net revenue of conventional (sun-grown) coffee plantations (30-fold decrease relative to the pre-crisis prices) than on the net revenue of the extensive agroforestry sites (2.9-fold decrease) and other shaded plantations (6.7-fold decrease). Concluding, although coffee and cocoa yield are presumed to be lower for shaded-systems, income from other products is expected to compensate for such losses while reducing farmers' vulnerability to the high price volatility of these two commodities, which should be included in financial analyses of these systems.

4.3. Trade-off Between Biodiversity Performance and Financial Performance

Although there are only few studies directly linking biodiversity performance and financial performance, there are indications that shaded systems potentially combine increases in both types of performance. As previously discussed, shade trees positively correlate with biodiversity thereby also increasing the matrix quality on landscape level (Schulze et al., 2004). In this review, we have attempted to analyse this relationship not only directly, but also indirectly, by discussing the relationships between the different biodiversity and financial performance indicators (Table 2).

4.3.1. Shade, Yield and Income

The influence of shade on the productivity of coffee and cocoa systems is highly debated and results are varied (Table 2). It is an important observation that some studies suggest a parabolic shaped relationship between yield and shade, indicating an excellent opportunity for shaded systems to increase financial performance. A fitted quadratic model from Waldron et al. (2012) suggests that for cocoa plantations the tipping point of maximum productivity lies around 144 shade trees per hectare, a relationship confirmed by studies indicating an optimum between approximately 20% and 50% of canopy closure. Similar debate accounts for the relationship between shade and income (Table 2). However, it should be noted that income in some of these studies is often a more or less direct result of productivity of the main cash crop, as the yield is frequently simply multiplied by the price received per unit of product. Yet, an optimum relationship between shade and yield would provide good opportunities to reconcile biodiversity conservation and local development in the tropics, where extensive conversion of tropical forest and agricultural intensification are identified as major drivers of biodiversity loss and of reduced associated ecosystem services, including coffee and cocoa production systems (Foley et al., 2011).

4.3.2. Biodiversity and Financial Performance

With regard to the relationship between species richness and financial performance, the results are even more divergent; they are often addressed in terms of yield and farmer income (Table 2). Clough et al. (2011) confirm that smallholders of cocoa agroforestry systems are able to combine high agricultural yield and high biodiversity goals on-farm, as they did not find a negative relationship between species diversity and income. An exclusion experiment on cocoa systems in Indonesia found the highest yield coinciding with high levels of ants (Wielgoss et al., 2014), indicating opportunities for increased income with a higher performance on biodiversity; this was also indicated by the study by Bisseleua et al. (2009). Even though there are only few studies directly linking biodiversity performance and financial performance, there are indications that shaded systems potentially combine increases in both types of performance (Somarriba and Beer, 2010; Staver et al., 2001). Besides direct monetary benefits, such as income from other products and a price premium, shaded coffee and cocoa systems generate other, often indirect, benefits for their owners. Although there are contradictory studies (e.g. Avelino et al., 2012), it has been found that moderate levels of shade can reduce disease (López-Bravo et al., 2012) and can hinder fungal disease by creating windbreaks which slow the horizontal spread of coffee leaf rust spores (Soto-Pinto et al., 2002). Furthermore, agroforestry systems can mitigate changes in temperature and precipitation (Lin, 2007), whilst the shade trees function as a nutrient safety net and natural provider of fertilizer (Tscharntke et al., 2011) and thereby enhance soil fertility. The latter finding will limit the input of agrochemicals, which is especially important for smallholders in view of the rising prices of chemical fertilizer. To draw more accurate and robust conclusions, further research is needed that focuses on the trade-offs between economic and biodiversity performance, including both direct and indirect benefits.

4.4. Data Limitations and Recommendations for Future Research

Despite the growing body of evidence suggesting that shaded systems can offer competitive business opportunities for small-scale farmers, knowledge remains limited on the conditions necessary for shaded systems to be competitive. A few main obstacles for detailed and robust analyses have become apparent in this review. First of all, there are only a limited number of multidisciplinary studies that include both financial and biodiversity data. Secondly, although a great deal of literature focuses on shaded systems, these studies frequently lack a baseline, as a conventional reference system is not always included. For instance, there is a large body of literature on shaded coffee systems in Mexico, yet the majority of these empirical studies focus on either ecological or economic components, do not include a reference system or report on economic performance only in terms of coffee yield. Thirdly, the few studies that comply with the standards mentioned above often include different categories or indicators, and the data collection methods are not always transparent. Although there is a clear continuum of coffee and cocoa management practices, researchers often develop their own characterizations of shade management practices. For example, the most-cited coffee biodiversity studies include >25 names to describe coffee-management systems (Philpott et al., 2008). This limits the comparability across case studies, thus preventing robust conclusions, while at the same time essential details, such as shade and matrix quality are lacking. Yet, the importance of shade and matrix quality on the conservation of biodiversity should not be underestimated. A framework with a consistent terminology would allow for greater comparability across studies, leading to more robust, precise and conclusive findings. Further research is therefore recommended on the effects of agrochemicals and environmental conditions on productivity, as well as the relative contribution of family and hired labour to costs incurred.

5. Conclusion

Although the relationship between productivity and financial performance may be straightforward for intensified monoculture land-use systems, this paper shows that this relationship is more complicated for diversified systems such as shaded coffee and cocoa plantations. As profitability in terms of net revenue and cost-efficiency in terms of BCR were higher for shaded systems, this review indicates that shaded systems can offer competitive business opportunities in comparison to the expanding sun-grown conventional plantations, and that there is a growing body of literature supporting this hypothesis. By analysing financial performance as a direct derivative of productivity for shaded coffee and cocoa systems, as conventional approaches dictate, other direct and indirect benefits are excluded, such as income from the shade trees and the ecosystem services provided by the shade trees. Additionally, costs associated with different management systems are often excluded from the analysis. We therefore recommend using a more comprehensive indicator such as net revenue or BCR. A fruitful venue for further research would be to provide more insight into the relationship between the separate components of financial performance in relation to the management of shaded coffee and cocoa systems.

Despite a lack of consensus on financial performance of shaded coffee and cocoa systems, it is known that there is a positive relationship between shade trees and biodiversity. Furthermore, in this review we found indications that shaded systems can have a similar or even better financial performance than conventional systems, mainly due to lower costs and a higher price received for their products. Moreover, shaded systems are likely to contribute to greater economic stability of farmers' income, also due to opportunities to gain additional income from other products, which reduce sensitivity to price volatility. Although case and site-specific conditions need to be taken into account, we have shown that shaded systems offer great potential to reconcile biodiversity conservation and local development. To address the lack of data, further validation of this relationship is necessary. We emphasize the need for comparable, long-term multidisciplinary studies, to quantify both financial and biodiversity performance, as well as to gain greater insight into the opportunities and challenges for scaling up.

Acknowledgements

This project was funded by Hivos, a Dutch non-governmental organisation, through the Business for Biodiversity project. We are also grateful to Tropenbos International for additional financial support. We would also like to thank two anonymous reviewers for their insightful comments and revisions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ecolecon.2017.04.019.

References

van Asten, P.J.A., Wairegi, L.W.I., Mukasa, D., Uringi, N.O., 2011. Agronomic and economic benefits of coffee–banana intercropping in Uganda's smallholder farming systems. Agric. Syst. 104:326–334. http://dx.doi.org/10.1016/j.agsy.2010.12.004.

Atangana, A., Khasa, D., Chang, S., Degrande, A., 2014. Tropical Agroforestry. Tropical Agroforestry. Springer Netherlands, Dordrecht:pp. 35–47 http://dx.doi.org/10.1007/978-94-007-7723-1.

Avelino, J., Romero-Gurdián, A., Cruz-Cuellar, H.F., Declerck, F.A., 2012. Landscape context and scale differentially impact coffee leaf rust, coffee berry bore, and coffee root-knot nematodes. Ecol. Appl. 22, 584–596.

Barham, B.L., Weber, J.G., 2012. The economic sustainability of certified coffee: recent evidence from Mexico and Peru. World Dev. 40:1269–1279. http://dx.doi.org/10.1016/j.worlddev.2011.11.005.

Beer, J., Muschler, R., Kass, D., Somarriba, E., 1998. Shade management in coffee and cacao plantations. Agrofor. Syst. 38, 139–164.

Belsky, J.M., Siebert, S.F., 2003. Cultivating cacao: implications of sun-grown cacao on local food security and environmental sustainability. Agric. Hum. Values 20:277–285. http://dx.doi.org/10.1023/A:1026100714149.

Bhagwat, S.A., Willis, K.J., Birks, H.J.B., Whittaker, R.J., 2008. Agroforestry: a refuge for tropical biodiversity? Trends Ecol. Evol. 23:261–267. http://dx.doi.org/10.1016/j.tree.2008.01.005.

Bisseleua, Daghela, H.B., Fotio, D., Yede, Missoup, A.D., Vidal, S., 2013. Shade tree diversity, cocoa pest damage, yield compensating inputs and farmers' net returns in West Africa. PLoS One 8. http://dx.doi.org/10.1371/journal.pone.0056115.

Bisseleua, D.H.B., Missoup, A.D., Vidal, S., 2009. Biodiversity conservation, ecosystem functioning, and economic incentives under cocoa agroforestry intensification. Conserv. Biol. 23:1176–1184. http://dx.doi.org/10.1111/j.1523-1739.2009.01220.x.

Campanha, M.M., Henrique, R., Santos, S., De, G.B., Emília, H., Martinez, P., Lages, S., Garcia, R., 2004. Growth and yield of coffee plants in agroforestry and monoculture systems in Minas Gerais, Brazil. Agrofor. Syst. 63, 75–82.

Chandler, R.B., King, D.I., Raudales, R., Trubey, R., Chandler, C., Chávez, V.J.A., 2013. A small-scale land-sparing approach to conserving biological diversity in tropical agricultural landscapes. Conserv. Biol. 27:785–795. http://dx.doi.org/10.1111/cobi.12046.

Clough, Y., Barkmann, J., Juhrbandt, J., Kessler, M., Wanger, T.C., Anshary, A., Buchori, D., Cicuzza, D., Darras, K., Putra, D.D., Erasmi, S., Pitopang, R., Schmidt, C., Schulze, C.H., Seidel, D., Steffan-Dewenter, I., Stenchly, K., Vidal, S., Weist, M., Wielgoss, A.C., Tscharntke, T., 2011. Combining high biodiversity with high yields in tropical agroforests. Proc. Natl. Acad. Sci. U. S. A. 108:8311–8316. http://dx.doi.org/10.1073/pnas.1201800109.

Clough, Y., Faust, H., Tscharntke, T., 2009. Cacao boom and bust: sustainability of agroforests and opportunities for biodiversity conservation. Conserv. Lett. 2: 197–205. http://dx.doi.org/10.1111/j.1755-263X.2009.00072.x.

De Beenhouwer, M., Aerts, R., Honnay, O., 2013. A global meta-analysis of the biodiversity and ecosystem service benefits of coffee and cacao agroforestry. Agric. Ecosyst. Environ. 175:1–7. http://dx.doi.org/10.1016/j.agee.2013.05.003.

Faria, D., Paciencia, M.L.B., Dixo, M., Laps, R.R., Baumgarten, J., 2007. Ferns, frogs, lizards, birds and bats in forest fragments and shade cacao plantations in two contrasting landscapes in the Atlantic forest, Brazil. Biodivers. Conserv. 16:2335–2357. http://dx.doi.org/10.1007/s10531-007-9189-z.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. Nature 478:337–342. http://dx.doi.org/10.1038/nature10452.

Gabriel, D., Sait, S.M., Kunin, W.E., Benton, T.G., 2013. Food production vs. biodiversity: comparing organic and conventional agriculture. J. Appl. Ecol. 50:355–364. http://dx.doi.org/10.1111/1365-2664.12035.

Gardner, T.A., Barlow, J., Chazdon, R., Ewers, R.M., Harvey, C.A., Peres, C.A., Sodhi, N.S., 2009. Prospects for tropical forest biodiversity in a human-modified world. Ecol. Lett. 12:561–582. http://dx.doi.org/10.1111/j.1461-0248.2009.01294.x.

Gobbi, J.A., 2000. Is biodiversity-friendly coffee financially viable? An analysis of five different coffee production systems in western El Salvador. Ecol. Econ. 33:267–281. http://dx.doi.org/10.1016/S0921-8009(99)00147-0.

Gordon, C., Manson, R., Sundberg, J., Cruz-Angón, A., 2007. Biodiversity, profitability, and vegetation structure in a Mexican coffee agroecosystem. Agric. Ecosyst. Environ. 118: 256–266. http://dx.doi.org/10.1016/j.agee.2006.05.023.

Green, R.E., Cornell, S.J., Scharlemann, J.P.W., Balmford, A., 2005. Farming and the fate of wild nature. Science 307:550–555. http://dx.doi.org/10.1126/science.1106049.

Haggar, J., Jerez, R., Cuadra, L., Alvarado, U., Soto, G., 2012. Environmental and economic costs and benefits from sustainable certification of coffee in Nicaragua. Food Chain 2:24–41. http://dx.doi.org/10.3362/2046-1887.2012.004.

Harvey, C.A., Gonzalez, J., Somarriba, E., 2006. Dung beetle and terrestrial mammal diversity in forests, indigenous agroforestry systems and plantain monocultures in Talamanca, Costa Rica. Biodivers. Conserv. 15:555–585. http://dx.doi.org/10.1007/s10531-005-2088-2.

Harvey, C.A., Komar, O., Chazdon, R., Ferguson, B.G., Finegan, B., Griffith, D.M., Martínez-Ramos, M., Morales, H., Nigh, R., Soto-Pinto, L., van Breugel, M., Wishnie, M., 2008. Integrating agricultural landscapes with biodiversity conservation in the Mesoamerican hotspot. Conserv. Biol. 22:8–15. http://dx.doi.org/10.1111/j.1523-1739.2007.00863.x.

Hicks, A., 2002. Post-harvest processing and quality assurance for speciality organic coffee products. AU J. Technol. 5.

Hoekstra, D.A., 1987. Economics of agroforestry. Agrofor. Syst. 300, 293–300.

ICC, 2014. World coffee trade (1963–2013): a review of the markets, challenges and opportunities facing the sector. Review of the 112th International Coffee Council. International Coffee Organization, London, p. 29.

Jha, S., Bacon, C.M., Philpott, S.M., Ernesto Mendez, V., Laderach, P., Rice, R.A., 2014. Shade coffee: update on a disappearing refuge for biodiversity. Bioscience 64:416–428. http://dx.doi.org/10.1093/biosci/biu038.

Juhrbandt, J., 2010. Economic valuation of land use change - a case study on rainforest conversion and agroforestry intensification in Central Sulawesi. (Indonesia Dissertation Jana Juhrbandt). Georg-August-Universität Göttingen.

Lin, B.B., 2007. Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. Agric. For. Meteorol. 144:85–94. http://dx.doi.org/10.1016/j.agrformet.2006.12.009.

López-Bravo, D.F., Virginio-Filho, E.D.M., Avelino, J., 2012. Shade is conducive to coffee rust as compared to full sun exposure under standardized fruit load conditions. Crop. Prot. 38:21–29. http://dx.doi.org/10.1016/j.cropro.2012.03.011.

Lyngbæk, A.E., Muschler, R.G., Sinclair, F.L., 2001. Productivity and profitability of multistrata organic versus conventional coffee farms in Costa Rica. Agrofor. Syst. 53, 205–213.

Marín, L., Philpott, S.M., De la Mora, A., Ibarra Núñez, G., Tryban, S., Perfecto, I., 2016. Response of ground spiders to local and landscape factors in a Mexican coffee landscape. Agric. Ecosyst. Environ. 222:80–92. http://dx.doi.org/10.1016/j.agee.2016.01.051.

Moguel, P., Toledo, V.M., 1999. Biodiversity conservation in traditional coffee systems of Mexico. Conserv. Biol. 13:11–21. http://dx.doi.org/10.1046/j.1523-1739.1999.97153.x.

Muschler, R.G., 2001. Shade improves coffee quality in a sub-optimal coffee zone of Costa Rica. Agrofor. Syst. 85, 131–139.

O'Brien, Timothy, G., Kinnaird, M.F., 2003. Caffeine and conservation. Science 300:587. http://dx.doi.org/10.1126/science.1082328 (80-.).

Ovalle-Rivera, O., Läderach, P., Bunn, C., Obersteiner, M., Schroth, G., 2015. Projected shifts in *Coffea arabica* suitability among major global producing regions due to climate change. PLoS One 10, e0124155. http://dx.doi.org/10.1371/journal.pone.0124155.

Pannell, D.J., 1999. Social and economic challenges in the development of complex farming systems. Agrofor. Syst. 45, 393–409 (doi:A2).

Perfecto, I., Mas, A., Dietsch, T., Vandermeer, J., 2003. Conservation of biodiversity in coffee agroecosystems: a tri-taxa comparison in southern Mexico. Biodivers. Conserv. 12, 1239–1252.

Perfecto, I., Vandermeer, J., 2008. Biodiversity conservation in tropical agroecosystems: a new conservation paradigm. Ann. N. Y. Acad. Sci. 1134:173–200. http://dx.doi.org/10.1196/annals.1439.011.

Perfecto, I., Vandermeer, J., Mas, A., Pinto, L.S., 2005. Biodiversity, yield, and shade coffee certification. Ecol. Econ. 54:435–446. http://dx.doi.org/10.1016/j.ecolecon.2004.10.009.

Phalan, B., Onial, M., Balmford, A., Green, R.E., 2011. Reconciling food production and biodiversity conservation: land sharing and land sparing compared. Science 333: 1289–1291. http://dx.doi.org/10.1126/science.1208742.

Philpott, S.M., Bichier, P., Rice, R., Greenberg, R., 2007. Field-testing ecological and economic benefits of coffee certification programs. Conserv. Biol. 21:975–985. http://dx.doi.org/10.1111/j.1523-1739.2007.00728.x.

Philpott, S.M., Bichier, P., Rice, R.A., Greenberg, R., 2008. Biodiversity conservation, yield, and alternative products in coffee agroecosystems in Sumatra, Indonesia. Biodivers. Conserv. 17:1805–1820. http://dx.doi.org/10.1007/s10531-007-9267-2.

Ponte, S., 2002. The 'Latte Revolution'? Regulation, markets and consumption in the global coffee chain. World Dev. 30:1099–1122. http://dx.doi.org/10.1016/S0305-750X(02)00032-3.

R Core Team, 2014. A language and environment for statistical computing. R Foundation for Statistical Computing.

Rice, R.A., 2008. Agricultural intensification within agroforestry: the case of coffee and wood products. Agric. Ecosyst. Environ. 128:212–218. http://dx.doi.org/10.1016/j.agee.2008.06.007.

Rice, R.A., Greenberg, R., 2000. Cacao cultivation and the conservation of biological diversity. AMBIO J. Hum. Environ. 29, 167–173.

Souza, H.N., Cardoso, I.M., Fernandes, J.M., Garcia, F.C.P., Bonfim, V.R., Santos, A.C., Carvalho, A.F., Mendonça, E.S., 2010. Selection of native trees for intercropping with coffee in the Atlantic Rainforest biome. Agrofor. Syst. 80:1–16. http://dx.doi.org/10.1007/s10457-010-9340-9.

Scherr, S.J., McNeely, J.A., 2008. Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 363:477–494. http://dx.doi.org/10.1098/rstb.2007.2165.

Schroth, G., da Fonseca, G.A.B., Harvey, C.A., Gascon, C., Vasconcelos, H.L., Izac, A.N., 2004. Agroforestry and Biodiversity Conservation in Tropical Landscapes. Island Press, Washington, DC.

Schroth, G., Harvey, C.A., 2007. Biodiversity conservation in cocoa production landscapes: an overview. Biodivers. Conserv. 16:2237–2244. http://dx.doi.org/10.1007/s10531-007-9195-1.

Schulze, C.H., Waltert, M., Kessler, P.J.A., Pitopang, R., Shahabuddin, S., Veddeler, D., Muhlenberg, M., Gradstein, S.R., Leuschner, C., Steffan-Dewenter, I., Tscharntke, T., 2004. Biodiversity Indicator groups of tropical land-use systems: comparing plants, birds and insects. Ecol. Appl. 14, 1321–1333.

Seufert, V., Ramankutty, N., Foley, J.A., 2012. Comparing the yields of organic and conventional agriculture. Nature 485:229–232. http://dx.doi.org/10.1038/nature11069.

Siebert, S.F., 2002. From shade- to sun-grown perennial crops in Sulawesi, Indonesia: implications for biodiversity conservation and soil fertility. Biodivers. Conserv. 11, 1889–1902.

Somarriba, E., Beer, J., 2010. Productivity of *Theobroma cacao* agroforestry systems with timber or legume service shade trees. Agrofor. Syst. 81:109–121. http://dx.doi.org/10.1007/s10457-010-9364-1.

Soto-Pinto, L., Perfecto, I., Caballero-Nieto, J., 2002. Shade over coffee: its effects on berry borer, leaf rust and spontaneous herbs in Chiapas, Mexico. Agrofor. Syst. 55, 37–45.

Soto-Pinto, L., Perfecto, I., Castillo-Hernandez, J., Caballero-Nieto, J., 2000. Shade effect on coffee production at the northern Tzeltal zone of the state of Chiapas, Mexico. Agric. Ecosyst. Environ. 80:61–69. http://dx.doi.org/10.1016/S0167-8809(00)00134-1.

Staver, C., Guharay, F., Monterroso, D., Muschler, R.G., 2001. Designing pest-suppressive multistrata perennial crop systems: shade-grown coffee in Central America. Agrofor. Syst. 53, 151–170.

Steffan-Dewenter, I., Kessler, M., Barkmann, J., Bos, M.M., Buchori, D., Erasmi, S., Faust, H., Gerold, G., Glenk, K., Gradstein, S.R., Guhardja, E., Harteveld, M., Hertel, D., Höhn, P., Kappas, M., Köhler, S., Leuschner, C., Maertens, M., Marggraf, R., Migge-Kleian, S., Mogea, J., Pitopang, R., Schaefer, M., Schwarze, S., Sporn, S.G., Steingrebe, A., Tjitrosoedirdjo, S.S., Tjitrosoemito, S., Twele, A., Weber, R., Woltmann, L., Zeller, M., Tscharntke, T., 2007. Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. Proc. Natl. Acad. Sci. U. S. A. 104:4973–4978. http://dx.doi.org/10.1073/pnas.0608409104.

Tscharntke, T., Clough, Y., Bhagwat, S.A., Buchori, D., Faust, H., Hertel, D., Ho, D., Juhrbandt, J., Kessler, M., Perfecto, I., Scherber, C., Hölscher, D., Juhrbandt, J., Kessler, M., Perfecto, I., Scherber, C., Schroth, G., Veldkamp, E., Wanger, T.C., 2011. Multifunctional shade-tree management in tropical agroforestry landscapes - a review. J. Appl. Ecol. 48: 619–629. http://dx.doi.org/10.1111/j.1365-2664.2010.01939.x.

Tscharntke, T., Clough, Y., Wanger, T.C., Jackson, L., Motzke, I., Perfecto, I., Vandermeer, J., Whitbread, A., 2012. Global food security, biodiversity conservation and the future of agricultural intensification. Biol. Conserv. 151:53–59. http://dx.doi.org/10.1016/j.biocon.2012.01.068.

Vaast, P., Bertrand, B., Perriot, J.-J., Guyot, B., Génard, M., 2006. Fruit thinning and shade improve bean characteristics and beverage quality of coffee (*Coffea arabica* L.) under optimal conditions. J. Sci. Food Agric. 86:197–204. http://dx.doi.org/10.1002/jsfa.2338.

Waldron, A., Justicia, R., Smith, L., Sanchez, M., 2012. Conservation through chocolate: a win-win for biodiversity and farmers in Ecuador's lowland tropics. Conserv. Lett. 5: 213–221. http://dx.doi.org/10.1111/j.1755-263X.2012.00230.x.

Wielgoss, A., Tscharntke, T., Rumede, A., Fiala, B., Seidel, H., Shahabuddin, S., 2014. Interaction complexity matters: disentangling services and disservices of ant communities driving yield in tropical agroecosystems. Royal Society. 281:pp. 2013–2144. http://dx.doi.org/10.1098/rspb.2013.2144.