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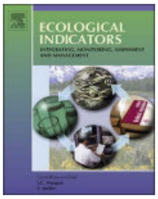

Environmental-economic benefits and trade-offs on sustainably certified coffee farms

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ABSTRACT

Coffee with diverse shade trees is recognized as conserving greater biodiversity than more intensive production methods. Sustainable certification has been proposed as an incentive to conserve shade grown coffee. With 40% of global coffee production certified as sustainable, evidence is needed to demonstrate whether certification supports the environmental benefits of shade coffee. Environmental and economic data were taken from 278 coffee farms in Nicaragua divided between non-certified and five different sustainable certifications. Farms were propensity-score matched by altitude, area of coffee and farmer education to ensure comparability between non-certified and certified farms. Farms under all certifications had better environmental characteristics than non-certified for some indicators, but none were better for all indicators. Certified farms generally received better prices than non-certified farms. Farms with different certifications had different investment strategies; C.A.F.E. Practice farms had high investment and high return strategies, while Utz and Organic farms had low investment, low productivity strategies. Tree diversity was inversely related to productivity, price and net revenue in general, but not for certified farms that received higher prices. Certification differentiates farms with better environmental characteristics and management, provides some economic benefits to most farmers, and may contribute to mitigating environment/economic trade-offs.

1. Introduction

The expansion of tropical agricultural commodities, such as coffee, has been seen as one of the major threats to biodiversity (Lenzen et al., 2012; Donald 2004). At the same time, other authors have proposed that promoting sustainable and diverse agricultural landscapes can be part of the solution to conserving biodiversity in hotspots such as Mesoamerica (Harvey et al., 2008). Many authors have presented and promoted the potential of coffee with diverse shade trees to sustain biodiversity of birds, ants, bats and other mammals (e.g. Greenberg et al., 2000; Mas and Dietsch 2004; Estrada et al., 2006). Intensification of traditional coffee production systems, i.e. reduction in use or diversity of shade trees and increased use of agrochemicals, has been seen as a threat to biodiversity in this region (Rice and Ward 1996). Philpott et al. (2008) synthesizing evidence from across Latin America found a consistent trend that both ant and bird species diversity declined (and especially forest species) when shade tree diversity and complexity were reduced. Furthermore, diverse shaded coffee systems have also been deforested and converted to other land uses especially during periods of low coffee prices (e.g. Blackman et al., 2008 in Mexico and Haggar et al., 2013 in Guatemala).

Diverse shaded coffee systems are generally less productive than systems with single species or no shade, and economic incentives may be required to conserve them (Philpott and Dietsch 2003). One way to promote the conservation of diverse shaded coffee is through sustainable certification to access preferential prices among buyers and consumers (Dietsch et al., 2004). The area of certified coffee has grown substantially over the past decade. Potts et al. (2014) estimate that 40% of the volume of global coffee production, although only 12% of sales, is sustainably certified; this comes from approximately 3 million ha or about 30% of global coffee area.

The sustainability standards (e.g. organic, Fairtrade, Rainforest, Utz Certified etc.) differ in the aspects they emphasise (see Milder et al., 2014, a summary is given in the supplementary information), but general they all seek to reduce or eliminate negative environmental and social factors. Each standard has its own way of assessing compliance. In general, there are a limited number of prohibited practices e.g. no use of synthetic agrochemicals in organic, no deforestation under Rainforest Alliance. Additionally, a certain percentage of a larger number of environmental and social criteria need to be met. This

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means that actual compliance with specific criteria can be very variable across farms. For example, while all standards have criteria for shade grown coffee for which farmers gain points, it is in theory possible to be certified under any of the standards without shade if enough other environmental criteria are met.

The conservation of higher carbon stocks in shaded coffee has been claimed as another benefit of sustainably certified coffee. Carbon stocks vary quite widely (from 20 to 150 t ha^{-1} above ground carbon) but generally are found to be intermediate between agricultural and forestry systems (as summarized in Idol et al., 2011). Some sustainability certification bodies, such as Rainforest Alliance, are exploring how to increase the benefits to farmers from the sale of additional ecosystem services, such as carbon sequestration (Rainforest Alliance 2009).

Blackman and Rivera (2011) reviewed studies of the impacts of sustainability standards but found only two studies of the environmental effects of these standards in coffee, and none found evidence of clear benefits. Milder et al. (2014) identified further limitations in previous studies such as the lack of counterfactuals, limited scale of sampling, evaluation of only one dimension of sustainability (e.g. environmental or economic) and indicators based on perception.

The current study addresses some of these limitations through a large-scale survey of 278 farms across Nicaragua, and seeks to determine:

- whether sustainable certification effectively differentiates between coffee farms with different environmental characteristics;
- whether certification provides an economic benefit to the farmer for providing these environmental services;
- whether there are trade-offs between environmental services and productivity or income and if so, whether certification mitigates these trade-offs.

These questions respond to two areas identified by Milder et al. (2014) as priorities for understanding the interactions of sustainability standards and conservation: the effects on ecosystems services, and the nature of conservation/productivity trade-offs.

2. Methods

2.1. Economic and environmental evaluation of farms

We used the Committee for Sustainability Assessment (COSA) method for multi-criteria assessment of sustainability in coffee (Giovannucci and Potts 2008) to evaluate environmental characteristics and production costs and farm income on farms with different sustainability certifications in Nicaragua. This method seeks to use indicators that can be evaluated by trained evaluators but non-specialists (i.e. people with a technical training but not economists nor environmental scientists). It also aims for a method that can be implemented in between half to one day per farm; while this limits the depth of evaluation it also permits larger samples sizes to be undertaken. While we recognize the importance of assessing outcomes (Milder et al., 2014), and the indicators chosen were as close to the outcome as feasible, in the case of soil and water conservation the only viable option found was to assess practices that should lead to outcomes (e.g. assessing how potential water contaminants are treated rather than assessing the water quality). Nevertheless, this evaluation still serves to confirm whether there is differential implementation of good management practices between non-certified and certified farms, especially as many of these practices are not mandatory, but contribute to a score across a larger number of the standard criteria.

Nicaragua was chosen as having a relatively compact and homogenous coffee production area that allows comparison of certifications under similar environmental and socioeconomic conditions. Although a small coffee producer (less than 2% of global production) it has been one of the pioneering countries in organic and Fairtrade certification (Bacon, 2005) and both small-scale and large-scale farmers use the major certification standards.

We conducted surveys across the main coffee producing departments of Central-Northern Nicaragua (Esteli, Jinotega, Madriz, Matagalpa and Nueva Segovias). We aimed to survey 80 non-certified farms plus 40 farms from each of five certifications: C.A.F.E. Practices, Fairtrade, organic (also Fairtrade certified), Rainforest Alliance and Utz certified (a summary of the main characteristics of each is provided in the Supplementary Information). Cooperatives or coffee traders provided lists of certified farms; non-certified coffee farms of similar size were identified in the same communities as the certified farms by asking local traders or the farmers themselves. The sampling of non-certified farms from the same community as the certified was to facilitate the matching using propensity scoring (see Section 2.2) by increasing the likelihood of the farms being under comparable conditions, but presence in the same community was not the basis for the matching. Due to availability of certified farms, surveys were conducted on 81 non-certified farms and between 35 and 48 farms for each certification, with a total of 294 farms evaluated. Two surveyors experienced in farm verification processes conducted the farmer questionnaires. We provided training and constant revision and feedback on the content and quality of the questionnaire to ensure consistency in application of the criteria for evaluation. The questionnaire covered general farm and environmental characteristics, productivity, production costs and revenue. General farm characteristics included farm size, area in coffee production, farm altitude, farmer educational level, and years of experience of the farmer producing coffee, amongst others.

Due to the large number of farms and time that could be dedicated evaluation of the farms consisted of visual observation or simple field measurements to assess environmental characteristics and management. The evaluation only considered the area of the farm under coffee plantation; other aspects of land-use on the farm were not included.

Environmental services were evaluated in four aspects.

- Habitat quality in terms of number of trees per ha, the total number of tree species in the coffee plantation and the number of tree strata were assessed by surveyors making visual counts or estimates in the field but also validating with the farmer's knowledge. Tree diameter was also measured for a small sample of trees (see carbon stock estimation below). These indicators show how similar the shade-tree structure is to a forest and are derived from those used by the Smithsonian Migratory Bird Centre (SMBC, no date) to determine bird-friendly coffee shade systems based on research by Greenberg et al. (1997). The number of tree species is obviously dependent on the area under coffee production. To take this into account we used an adaptation of the Margalef diversity index (Magurran 2004) which compensates for the degree of sampling effort by dividing the number of species − 1 by the log of the number of individuals sampled. In our case, we considered the area of the coffee plantation to be more accurate as a measure of sampling effort than the estimated tree population (tree population is affected by tree planting of 1 or 2 species by the farmers, while species richness is affected occurrence of wild trees which we consider a function of area). Additionally, to avoid negative logs, as some areas are less than 1 ha, ln(area + 1) was used as the denominator in the following equation:

$$\text{Tree diversity} = (\text{spp-1})/\ln(\text{area} + 1)$$

While both the Margalef index and this adaptation may be limited by the assumption of a natural log based relationship of species richness to population or area, the index has advantages over other diversity indices in being more heavily weighted to species richness (our primary interest) rather than the relative dominance across species included in other diversity indices (Magurran 2004). This index has also been widely used for site comparisons of species richness (Seaby and Henderson 2006).

- Carbon stock in trees was calculated based on the measurement of the diameter at breast height (dbh) of 10 trees in the centre of the coffee plantation. The 10 trees formed a contiguous group of trees (including all large or small individuals), selected to be typical of the shade in the plantation as a whole. Allometric equations were used to calculate biomass and C per tree from dbh. For trees up to 50 cm dbh the equation from Segura et al. (2006) was used and which was developed for shade trees in coffee in Nicaragua; for forest trees > 50 cm dbh the generic equation for tropical forest trees from Brown et al. (1989) was used; both are IPCC approved equations (IPCC, 2003). The average C stock per tree was multiplied by the tree density to estimate C stock per hectare.
- Soil conservation was evaluated using the following indicators:

(1) Estimation of ground cover was done using an adaptation of the point intercept method, whereby the observer walking through the plantation evaluates whether the soil at the “tip of their shoe” is bare soil, covered with plants or leaf litter (Guharay et al., 2000). The observer evaluates 10 points ten paces a part through the plantation, repeated at least 3 times per hectare of the plantation under evaluation for a minimum of 30 points.
(2) The use of soil conservation practices (i.e. live or dead barriers along the contours, micro-terracing, bunds, cut-off drains), recycling of coffee pulp and application of organic fertilizer were each registered as “yes” or “no” and visually verified by the surveyors.

- Conservation of water quality was evaluated by registering as “yes” or “no” to the following actions: reduction in water used for processing (e.g. use of ecological wet processer), avoidance of application of pesticides near water sources, treatment of waste water from washing coffee (i.e. treated away from water sources) and treatment of domestic waste water (i.e. does not enter water sources). These are all physical infrastructure or equipment factors that were verified by the surveyors.

We used the COSA questionnaires to register all coffee management practices and estimate the costs of those practices as well as the amount of coffee produced and value of sales for the previous year. The format is designed to facilitate the reconstruction of costs from farmer recollection by working through the practices for the farming year; this is supported by the registers of activities and use of records farmers are required to maintain when they are certified, but are less common for non-certified farmers.

The aim was to estimate net revenue from the coffee production system based on the calculation of the cash-flow for one year. The costs considered are largely variable costs, although some fixed costs such as equipment depreciation and taxes are included. For agronomic labour the number of person-days and cost per day were registered for all management practices (i.e. fertilization, pest-control, shade management, pruning, soil conservation measures and weeding). Then the cost of inputs or equipment for these practices was registered (e.g. fertilizer, pesticides, machetes etc) noting the volume or number of the product and the cost per unit. Costs of labour for the harvest and processing were calculated (including picking, wet processing, and drying) based on a cost per volume of harvest (as this is how these services were usually paid). The amount and price of materials, tools and equipment used in harvest and processing were registered; in the case of the equipment cost the total cost was divided by the life-span of a piece of equipment, as an estimate of the deprecation value. Finally, additional costs were registered including, fuel used (for machinery), transport costs, interest on loans and taxes paid.

These costs were summed to estimate a cost per hectare of production. Farms where costs were incomplete or they substantially deviated from the normal range of values were eliminated from the analysis; data from a total of 278 of the 294 farms surveyed were included in the economic analyses (Table 2). Some of the analyses below use the total costs of production per hectare summing all the factors above, other analyses just use the agronomic costs (labour and inputs invested in managing the coffee pre-harvest) as a measure of the investment coffee productivity.

We also asked farmers the amount of coffee sold and price obtained, or in the case of sales at different prices the volume and price of each lot, to calculate the gross revenue from coffee. Finally, net revenue was calculated as the differences between the costs per hectare and the gross revenue per hectare from coffee.

2.2. Data analysis

Blackman and Rivera (2011) have criticized many studies of the effects of sustainable certifications for not ensuring comparability between certified and non-certified farms. They recommended the use of propensity score matching to ensure that comparability. To identify the parameters against which to match we selected farm characteristics that would have been determined prior to certification such as farm size, area in coffee, altitude, age of farmer, education level of the farmer. These parameters were evaluated for their relevance by conducting multiple regressions against the variables for economic or environmental performance (using Infostat, Di Rienzo et al., 2008). The economic response variables productivity, production costs and net revenue had significant correlations ($p < 0.01$) with area under coffee, altitude, and level of education of farmer. Area under coffee, altitude and education were taken as the matching parameters in propensity scoring to define the population of non-certified farms to be compared with each group of certified farms with respect to differences in their economic performance (using STATA version 10, StataCorp., 2007). T-tests were conducted showing there was no significant difference after matching between certified and non-certified farms for the matching variables (see Supplementary Information section B). It should be noted that this analysis compares each certification against its non-certified matched control, but does not compare between the different certifications.

No significant regressions of environmental service variables were found with farm characteristics so analyses comparing certified and non-certified farm environmental performance were conducted using analysis of variance for those parameters that were continuous variables (i.e. tree density, tree species diversity, tree basal area, carbon stocks and plant ground cover), also checking distribution of residuals using the Shapiro Wilks test in Infostat. For environmental parameters that were classified variables (i.e. indicators of soil and water conservation, or number of tree strata), relationships with the certification status of the farms were analysed using correspondence analysis.

Individual relationships between agro-economic (productivity, costs of production and net revenue) and environmental variables (tree diversity and carbon stocks) were tested using linear regressions and between price and the same environmental variables using Spearman rank correlation. Multiple regressions were used to test the relative contributions of different factors (economic and environmental) to economic performance.

3. Results

3.1. Environmental variables

3.1.1. Indicators of habitat quality

Farm certification had a highly significant effect on the Margalef index of tree diversity ($p < 0.001$), with farms certified C.A.F.E. Practices having significantly lower diversity than organic farms,

Table 1
Environmental performance of farms under different certifications. Means for certifications with different letters are significantly different to $p < 0.05$ using the Tukey test.

Certification	Tree density Trees ha^{-1}	Tree basal area m^2 tree^{-1}	% farms with 3 tree strata	Margalef tree diversity index	Above ground C t ha^{-1}	% plant ground cover
Non-certified	78.6 a	0.18 a	43	2.79 a	82 a	74.3 a
C.A.F.E. Practices	103.3 a	0.17 a	44	2.30 a	101 a	77.1 a
Fairtrade	90.7 a	0.20 ab	55	4.58 ab	90 a	78.9 ab
Organic + Fairtrade	108.0 a	0.18 a	66	5.25 b	110 a	77.2 a
Rainforest	91.4 a	0.27 b	62	2.94 ab	150 a	88.3 b
Utz Certified	97.1 a	0.26 ab	58	4.57 ab	146 a	81.5 ab
L.S.D. ($p < 0.05$)	37.2	0.08		2.47	77	11.0
Chi-square			$p < 0.05$			

Table 2
Farm characteristics and coffee price under different certifications. Letters indicate significantly different means between certifications as tested by Tukey means test ($p < 0.05$).

Certification	Number of farms surveyed	Altitude m.a.s.l.	Coffee Area ha	Educational level[a]	Average Price[b] US \$ kg^{-1}
Non-certified	76	1031 bc	14.2 a	2.9 a	2.19 a
C.A.F.E. Practices	44	1139 c	39.0 bc	4.2 b	2.57 b
Fairtrade	43	992 b	3.4 a	3.0 a	2.53 b
Organic + Fairtrade	47	996 b	4.3 a	3.2 a	2.81 c
Rainforest Alliance	33	998 b	50.6 c	3.2 a	2.62 bc
Utz	35	747 a	16.8 ab	4.2 b	1.99 a
L.S.D. ($p < 0.05$)		123	23.9	0.8	0.24

[a] 3 = Primary completed, 4 = Secondary, 5 = Technical College.

[b] Price is averaged across both certified and non-certified sales of coffee; note few farms manage to sell all their coffee as certified.

although neither were significantly different from non-certified farms (Table 1).

The frequency coffee plantations with one, two or three tree strata was significantly affected by certification status of the farm (chi-square $p < 0.05$); with over 60% Organic and Rainforest having 3 strata, as opposed to 2 strata in the majority of C.A.F.E. Practices and non-certified farms (Table 1).

Tree density showed no significant difference between certifications, but average tree basal area was significantly different ($p < 0.007$) with trees on Rainforest Alliance farms having significantly greater basal area than on C.A.F.E. Practices, organic or non-certified farms (Table 1).

3.1.2. Tree carbon-stocks

Stand basal area and the above ground carbon stocks were significantly affected by certification ($p = 0.011$). Although the Tukey means comparison did not identify differences between specific certifications, the trend was for certified farms, and especially the Utz and Rainforest farms, to have greater carbon stocks than the non-certified farms (Table 1).

3.1.3. Soil and water conservation

Ground cover was significantly related to certification status ($p < 0.01$), but only Rainforest Alliance farms had significantly higher plant ground cover than non-certified farms in pair-wise comparisons (Table 1). Correspondence analysis indicated that use of soil conservation practices, recycling of coffee pulp and application of organic fertilizers were more closely associated with certified farm types (Fig. 1), with over 75%, 83% and 60% of certified farms and 50%, 63% and 35% of non-certified farms respectively applying these practices. Non-certified farms were associated with a lack of management of sources of water contamination, and for some criteria also Fairtrade farms. Organic, Rainforest Alliance, C.A.F.E. Practices and Utz had at least 20% more farms who reduced the volume of water used for coffee processing and had good management of waste water contaminated from coffee processing or domestic sources compared to non-certified farms (Fig. 2).

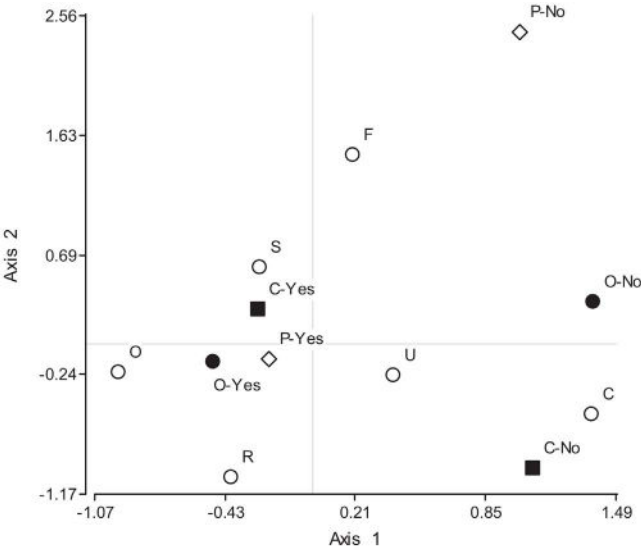

Fig. 1. Correspondence analysis between implementation of soil conservation practices and certification status. Key: ○ = Certification: C = Non-certified F = Fairtrade, O = Organic, R = Rainforest Alliance, S = C.A.F.E. Practices, U = Utz; ■ = Soil Conservation Practices implemented: C-No, C-Yes; ◊ = Coffee pulp recycled P-No, P-Yes; ● = Organic fertilizer applied O-No, O-Yes.

3.2. Economic variables

Farm characteristics were significantly different between different certifications (Table 2) e.g. organic and Fairtrade farms had smaller areas under coffee than Rainforest Alliance and C.A.F.E. Practices farms; Utz farms had lower altitude than C.A.F.E. Practices farms; organic, non-certified and Fairtrade farmers only had primary education while Utz and C.A.F.E. Practices farmers tended to have secondary or technical education. This was confirmed by the logit models for the propensity score matching which showed significant differences between each certified group and the general non-certified population and thus the need to use the propensity score to select the populations with overlapping characteristics between the two groups for comparison. The differences in the performance of the non-certified farms selected for comparison with each certified group can be seen in Fig. 3.

The average price received by the farmer for their coffee was significantly affected by certification ($p < 0.001$). All certified farms, except those with Utz certification, had significantly higher sale price than non-certified farms, with organic plus Fairtrade having the highest price, 28% higher than non-certified. It should be noted that the Utz farms were from the lowest altitude (less than 800 m.a.s.l. on average) and probably had lower quality coffee, which may have affected the price received, although overall there was no significant correlation

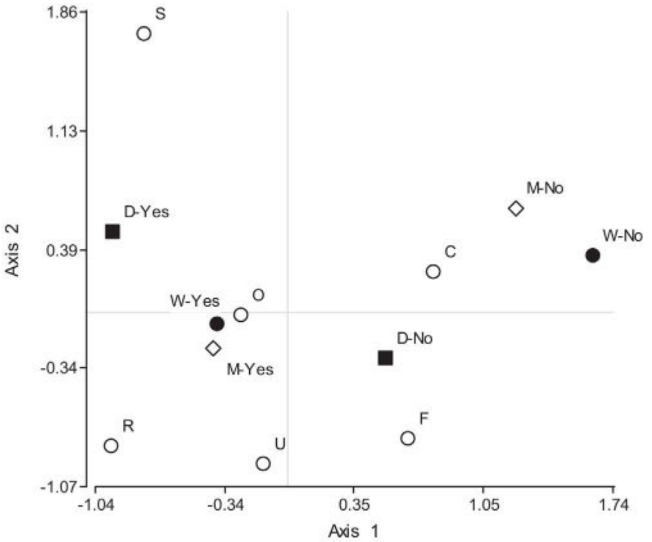

Fig. 2. Correspondence analysis between certification and different practices for management of water contamination (yes = good practice, no = no management). Key: ○ = Certification: C = Non-certified F = Fairtrade, O = Organic, R = Rainforest Alliance, S = C.A.F.E. Practices, U = Utz; ◊ = Reduced Water use: M-No, M-Yes; ■ = Domestic waste water treated: D-No, D-Yes; ● = Coffee washing water treated: W-No, W-Yes.

between price and altitude.

Comparison between certified and matched non-certified farms show that organic and Utz certified farms were 32 and 36% less productive than comparable non-certified farms (Fig. 3), while their costs of production were 25% and 50% less respectively than non-certified farms (though not significantly in the case of organic producers). Costs of production on C.A.F.E. Practice certified farms were 40% higher than non-certified, but this was only significant to p = 0.08. Net revenue was 48% higher on C.A.F.E. Practice farms and 43% higher on Fairtrade farms than non-certified, although the later was only significant to $p = 0.10$. Net revenue of organic farms was the same as non-certified, while net revenue on Utz farms was 44% lower than non-certified.

3.3. Environment/economic tradeoffs

Tree diversity and carbon stocks were negatively correlated with productivity and tree diversity was negatively correlated with net revenue when regressed across all farms (Fig. 4). Tree diversity had a negative correlation with coffee price (regression coefficient −0.17, $p < 0.001$), while carbon stocks had a weakly positive correlation (regression coefficient 0.11, $p = 0.05$). Nevertheless, tree diversity and carbon stocks were also negatively correlated to agronomic costs of production (regression coefficient $-495\, p < 0.001$; $-14.5\, p < 0.01$, respectively), i.e. farmers invested less in coffee production on farms with a higher tree diversity index and higher carbon stocks. As might be expected productivity and net revenue were also highly correlated with agronomic costs of production (regression coefficients 590 and 0.14 respectively, $p < 0.0001$). Thus, the lower production and net revenue in more tree diverse systems could be due to the lower investment in production in these systems.

To account for this, multiple regressions were conducted of

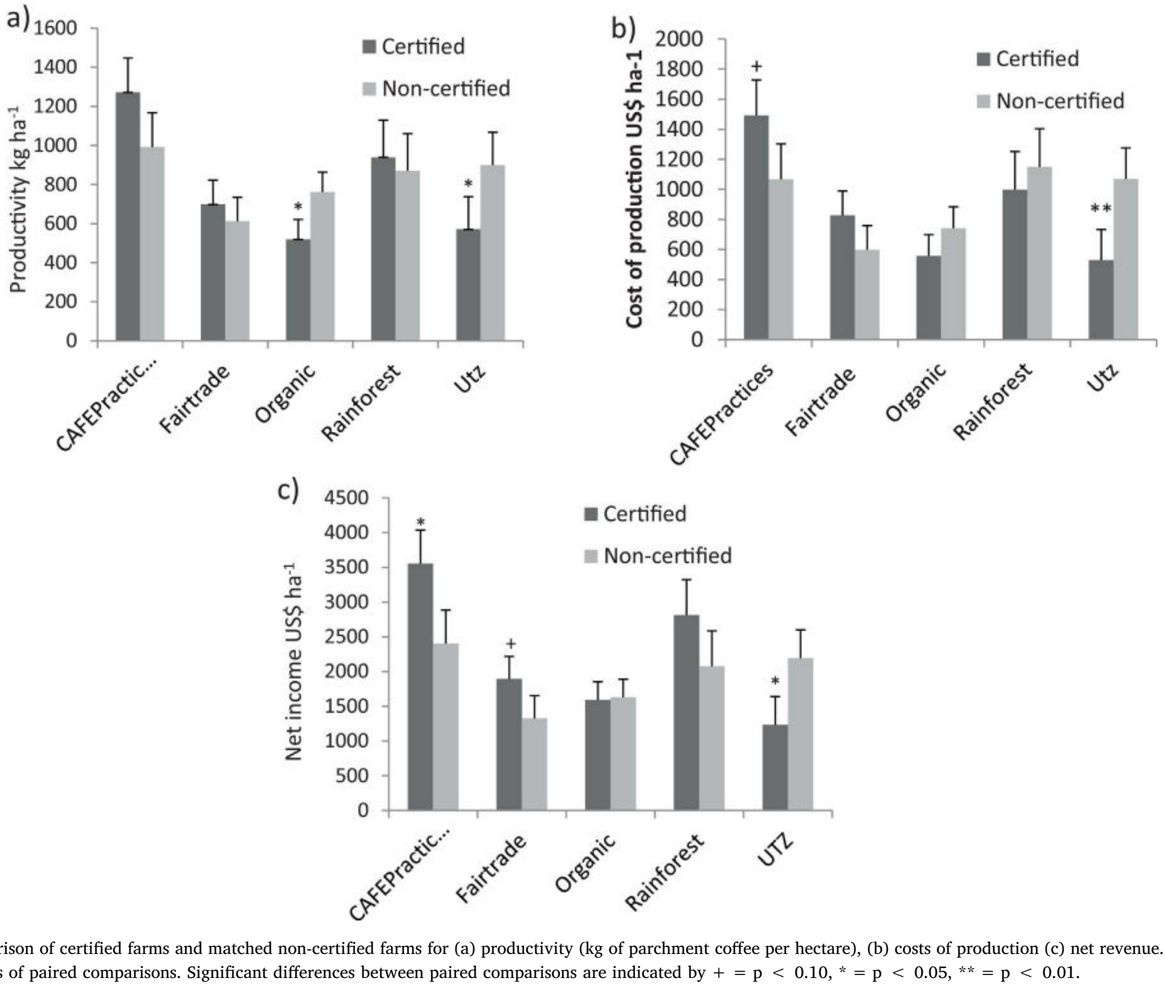

Fig. 3. Comparison of certified farms and matched non-certified farms for (a) productivity (kg of parchment coffee per hectare), (b) costs of production (c) net revenue. Error bars are standard errors of paired comparisons. Significant differences between paired comparisons are indicated by + = p < 0.10, * = p < 0.05, ** = p < 0.01.

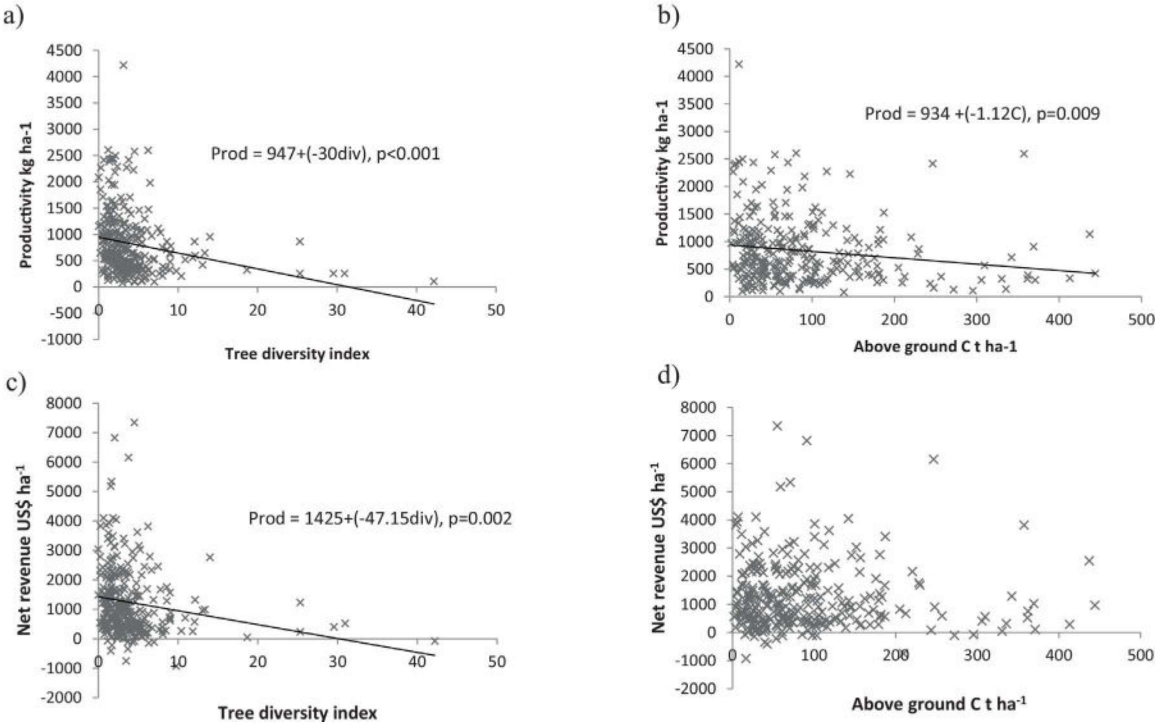

Fig. 4. Regressions between agro-economic (productivity and net revenue) and environmental (tree diversity and carbon stocks) performance. Significant regression lines and equations are shown.

productivity and net revenue against agronomic production costs (inputs and labour), tree diversity and carbon stocks. These multiple regressions firstly accounted for the effects of differences in agronomic costs on productivity and net revenue and then whether there was a significant residual effect of carbon stocks or tree diversity. These regressions did show a significant negative relationship between tree diversity and net revenue and weakly significant negative relationship with productivity (Table 3a), but no significant residual relationship of carbon stocks with these factors was found. When the farms were divided into those that received a price premium i.e. significantly higher price than non-certified (all certified farms other than those under Utz) and farms that did not (non-certified plus Utz farms), the former had no significant relationship between tree diversity and productivity nor net revenue; while the latter group had a significant negative relationship with both (Table 3b and c). Furthermore, the certified farms that received a premium had no significant correlation between tree diversity and price per kg of coffee; while for those that did not receive a premium, there was a significant negative correlation (-0.34, $p < 0.001$).

4. Discussion

4.1. Environmental services from certified farms

Farms under each certification had better environmental performance than non-certified farms for some environmental indicators, but no certification had better environmental performance under all indicators. It seems likely that habitat quality characteristics and carbon stocks are likely to have existed prior to being certified as these take time to develop, i.e. to allow large trees to develop or increase the diversity of mature trees takes decades to achieve. Other differences such as improved management practices to protect soil and water are more likely to be a result of compliance with certification standards.

Indicators of the similarity of the shade tree cover to forest – habitat quality – were better under some certifications and would indicate a capacity to support other fauna and flora. Gordon et al. (2007) found a significant correlation between bird species richness and abundance and shade cover and canopy height in coffee plantations. This agrees with Haggar et al. (2015) where organic farms in Nicaragua, Costa Rica and Guatemala were found to have greater tree diversity than non-organic farms. Philpott et al. (2007) studying organic and Fairtrade certified farms in Mexico found that most farms did not comply with the Bird Friendly shade-certification criteria (SMBC, no date), although organic farms had greater tree diversity than non-certified farms. There is some evidence in the current study that above ground carbon stocks were greater on some certified farms. Richards and Mendez (2014) in El Salvador found a positive correlation between tree diversity and carbon stocks, which was also the case in this study.

4.2. Economic benefits of sustainable certification

Farms with certifications had different pre-existing characteristics (i.e. characteristics not expected to be affected by certification) but some were related to eligibility to comply with the standard. For example, C.A.F.E. Practice only certifies farms with an altitude over 1000 masl and Fairtrade (and organic-Fairtrade) only certify small-scale organized producers. Beyond this there was a tendency for distinct typologies of farms to enter different certifications, e.g. larger-scale farmers enter Rainforest Alliance and C.A.F.E. Practice; while C.A.F.E. Practice and Utz farmers were more educated. This was further reinforced by the significance of the logit models for the propensity scoring that defined a distinct matched non-certified group of farms for each certified group, which can be seen when comparing the productivity and economic values for the matched non-certified populations, indicating each type of certified farmer comes from a different socio-economic group. Thus, it seems likely that the distinct economic performance of farms under different certifications was at least in part due to pre-existing differences. This may be related to the different institutional associations of the certifications. Fairtrade and organic certifications tend to have been promoted by NGOs and social enterprises that focus on smaller more disadvantaged farmers; while the other certifications have been largely implemented through coffee

Table 3
Multiple regression coefficients and standard errors of economic and environmental factors against productivity and net revenue.

(a) All farms

	Productivity kg ha^{-1}			Net revenue US\$ ha^{-1}		
	Coefficient	S.E.	p-value	Coefficient	S.E.	p-value
Agronomic costs US\$ ha^{-1}	$8.70e^{-04}$	$5.10e^{-05}$	< 0.0001	0.54	0.12	< 0.0001
Carbon t ha^{-1}	$-1.20e^{-03}$	$4.10e^{-03}$	0.7633	1.26	9.60	0.895
Tree Diversity	−0.23	0.12	0.065	−633.9	288.8	0.029

(b) Farms with premium price (C.A.F.E. Practices, Fairtrade, Organic and Rainforest Alliance)

	Productivity kg ha^{-1}			Net revenue US\$ ha^{-1}		
	Coefficient	S.E.	p-value	Coefficient	S.E.	p-value
Agronomic costs US\$ ha^{-1}	$9.0e^{-04}$	$8.40e^{-05}$	< 0.0001	0.71	0.21	< 0.001
Carbon t ha^{-1}	$8.4e^{-04}$	0.01	0.884	3.28	14.21	0.817
Tree Diversity	−0.17	0.15	0.245	−576.4	371.0	0.122

(c) Farms with no premium price (non-certified and Utz-certified)

	Productivity kg ha^{-1}			Net revenue US\$ ha^{-1}		
	Coefficient	S.E.	p-value	Coefficient	S.E.	p-value
Agronomic costs US\$ ha^{-1}	$8.3e^{-04}$	$5.9e^{-05}$	< 0.0001	0.34	0.10	0.002
Carbon t ha^{-1}	−0.01	0.01	0.3534	−7.88	9.65	0.416
Tree Diversity	−0.48	0.24	0.0515	−1054.3	425.9	0.015

traders who have focused (but not exclusively) on medium to larger scale farmers (pers obs).

Nevertheless, certified farms (a part from those under Utz) did receive better prices for their coffee than non-certified farms. Farms under different certifications appeared to have distinct investment strategies, e.g. organic and Utz farms with low investment – low productivity or C.A.F.E. Practice farms high-investment – high productivity strategies; it seems likely these distinct strategies respond to the different socioeconomic conditions of the farmers but also to the demands of the certification. For example, organic management is accessible to farmers with low capacity to invest in purchased inputs but the higher prices enabled them to achieve similar net revenue as non-certified farms for a lower production cost.

4.3. Economic-environmental trade-offs

In general, the price premium for certification does compensate farms that have positively different environmental management characteristics. Farms under three of the certifications (C.A.F.E. Practices, Fairtrade and Rainforest Alliance) had similar or higher productivity than matched farms, although Organic and Utz farms had lower productivity; but there was no evidence of a productivity/certification trade-off per se. Nevertheless, productivity was negatively correlated with carbon stocks and tree diversity.

While greater tree carbon stocks and therefore biomass would indicate potentially greater competition from the shade trees that could limit coffee productivity, it is less obvious why tree diversity should have a significant negative relationship on productivity (Fig. 4). Martinez-Torres (2008) found positive correlations between shade tree diversity and productivity, and Soto-Pinto et al. (2000) observed that tree density did not affect coffee yields, but both studies were conducted within a narrower range of production systems i.e. only in organic or low-input systems. Haggar et al. (2013) comparing across a broader range of production systems in Guatemala found that coffee had lower productivity on high shade-tree diversity farms.

There are potential trade-offs between high carbon stocks and productivity or net income from coffee production, which may vary considerably depending on the shade tree and coffee management (Noponen et al., 2013). Nevertheless, in the current study the economic trade-offs appeared to only be significant for tree diversity and not carbon stocks. One distinction with the Noponen study is that in this study at least some high-carbon stock farms were receiving higher prices for their certified coffee, but also Noponen et al. identified some production scenarios where high carbon stocks were compatible with high economic returns.

The tree diversity and carbon stock trade-offs with productivity is largely mediated by the lower level of investment in production by farmers with more diverse/higher carbon shade tree systems. Not surprisingly lower investment in production results in lower productivity and net revenue. The lower productivity of the higher diversity and tree carbon systems is largely due to these systems being managed under lower investment strategies. This could be due to farmers tailoring their levels of investment to the capacity of the agricultural systems capacity to respond, i.e. they don't invest in labour and inputs in high biodiversity/high tree carbon systems that are not capable of high productivity. Conversely high biodiversity/tree carbon systems may be an option to maintain low-investment systems that are still economically productive; many farmers in developing countries are limited in their access to financial resources to increase productivity (Gobbi 2000). Gordon et al. (2007) did find coffee plantations that combined high productivity with high tree diversity in Mexico and so did not find significant trade-offs between productivity or net revenue and biodiversity, although the total sample size was only 10 farms. The most productive of these Mexican plantations was only a third that of the most productive plantations found in the larger sample size from Nicaragua in this study. It has been recognized that generally highly managed systems tend to be less diverse, and the profitability of commodity crops tends to restrict the adoption of high diversity systems on large-scale plantations (Harvey and Villalobos, 2007).

Nevertheless, even after accounting for the tendency to invest less in the production of high-diversity/high carbon systems, there was still a negative relationship between productivity and net revenue with tree diversity. But this was not the same for all farms. Those certified farms that received a premium price did not demonstrate a significant trade-off between tree diversity and net revenue, once the level of investment in production was accounted for. Furthermore, for this group coffee price was positively associated with tree diversity, and not negatively associated as for farms that received no premium. Therefore, it would appear that the higher prices from most certifications were having the effect of compensating the lower return on investment normally received by producers with more diverse coffee systems.

5. Conclusion

While certification has been proposed as a means to provide incentives to farmers to conserve shaded coffee (e.g. Rice and Ward 1996; Dietsch et al., 2004), others have expressed reservations as to how effective certification is at translating consumer demand into specific conservation outcomes (Rappole et al., 2003). While overall the certified farms had a better environmental performance, and provide some economic benefit to farmers, this would appear to largely recognize pre-existing differences in farm management strategies. Nevertheless, the higher price paid for most certified coffee at least partially mitigates biodiversity/productivity trade-offs for the farmer, which could be an incentive to sustain otherwise less economically productive high biodiversity production systems. Longer term studies are required to ascertain whether the economic benefits of certification for farmers will lead to more farmers adapting their production practices to meet the certification requirements and provide an incentive for longer term improvements in the environmental services from sustainably certified farms.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2017.04.023.

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