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The use of Ecosystem-based Adaptation practices by smallholder farmers in Central America

Celia A. Harvey[a,*], M. Ruth Martínez-Rodríguez[a], José Mario Cárdenas'[b,1], Jacques Avelino[b,c,d], Bruno Rapidel[b,e], Raffaele Vignola[b,f], Camila I. Donatti[a], Sergio Vilchez-Mendoza[b]

[a] Conservation International, 2011 Crystal Drive, Suite 500, Arlington, VA, 22202, USA
[b] Tropical Agriculture Research and Higher Education Center (CATIE), Apdo. 7170, Turrialba, Costa Rica
[c] CIRAD, UR106 Bioagresseurs: Analyse et maîtrise du risque, TA A-106–Avenue Agropolis, 34398, Montpellier Cedex 5, France,
[d] IICA, AP 55, 2200 Coronado, San José, Costa Rica
[e] CIRAD, UMR SYSTEM, 34060, Montpellier, France
[f] Institute for Environment, Resources and Sustainability (IRES), University of British Columbia, Vancouver, Canada

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ABSTRACT

There is growing interest in promoting the use of Ecosystem-based Adaptation (EbA) practices to help smallholder farmers adapt to climate change, however there is limited information on how commonly these practices are used by smallholder farmers and what factors influence their use. Using participatory mapping and field surveys, we examined the prevalence and characteristics of EbA practices on 300 smallholder coffee and maize farmers in six landscapes in Central America and explored the socioeconomic and biophysical factors associated with their use. The prevalence of individual EbA practices varied across smallholder farms. Common EbA practices included live fences, home gardens, shade trees in coffee plantations, and dispersed trees in maize fields. We found a mean of 3.8 EbA practices per farm. Factors that were correlated with the total number of EbA practices on farms included the mean area of coffee plantations, farmer age, farmer experience, the farm type and the landscape in which farms were located. Factors associated with the presence or characteristics of individual EbA practices included the size of coffee plantations, farmer experience, farmer education, land tenure, landscape and farm type. Our analysis suggests that many smallholder farmers in Central America are already using certain EbA practices, but there is still scope for greater implementation. Policy makers, donors and technicians can encourage the broader use of EbA by smallholder farmers by facilitating farmer-to-farmer exchanges to share knowledge on EbA implementation, assessing the effectiveness of EbA practices in delivering adaptation benefits, and tailoring EbA policies and programs for smallholder farmers in different socioeconomic and biophysical contexts.

1. Introduction

Smallholder farmers are highly vulnerable to climate change due to their dependence on rain-fed agriculture, their small landholdings, their location in often remote and marginal lands, and their restricted access to technical expertise, credit and institutional support, which limits their ability to adapt to changing conditions (Morton, 2007; Vermeulen, 2014). Governments, policy makers, donors and practitioners have recognized the urgent need to help smallholder farmers build resilience to climate change and are actively developing strategies to make that happen (Dinesh et al., 2016; Vermeulen, 2014). Agriculture is also assuming greater prominence in both national and international policy discussions around climate adaptation and becoming a priority sector for action. For example, as of May 2016, 127 countries had highlighted the importance of adaptation in agriculture in their intended nationally determined contributions (INDCs) under the Paris Agreement of the UNFCCC (Richards et al., 2016), and policy discussions on how to prioritize agriculture as a sector for adaptation and mitigation under the UNFCCC are ongoing (Dinesh et al., 2016).

One approach which could help farmers adapt to climate change is the promotion of Ecosystem-based Adaptation (EbA). EbA refers to the use of ecosystem services and biodiversity as part of an overall

* Corresponding author.
E-mail addresses: charvey@conservation.org (C.A. Harvey), rmartinez@conservation.org (M.R. Martínez-Rodríguez), jcardenas@mag.go.cr (J.M. Cárdenas'), jacques.avelino@cirad.fr (J. Avelino), bruno.rapidel@cirad.fr (B. Rapidel), rvignola@catie.ac.cr (R. Vignola), cdonatti@conservation.org (C.I. Donatti), svilchez@catie.ac.cr (S. Vilchez-Mendoza).
[1] Present address: Ministerio de Agricultura y Ganadería (MAG, Costa Rica), Carara, Costa Rica.

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adaptation strategy to help people adapt to the negative impacts of climate change (Doswald et al., 2014; Munang et al., 2013). In the context of agriculture, EbA can include a variety of different practices that are based on the management of ecosystems, ecosystem services and biodiversity (Vignola et al., 2015). Common examples of EbA at the plot or farm scale include the use of agroforestry systems to buffer the impacts of high temperatures, heavy rains or other climate impacts on crops or livestock (e.g., Lin, 2007; Siles et al., 2010; Verchot et al., 2007), the establishment of windbreaks to reduce impacts of extremely strong winds (e.g., Easterling et al., 1997; Rosenberg, 1992), the use of soil conservation practices (e.g., use of cover crops, terracing) to prevent soil erosion and maintain soil fertility under heavy rainfall (Dabney, 1998; Erenstein, 2003), the establishment of live fences to prevent soil erosion and provide fodder to cattle during the dry season (Harvey et al., 2005), and the diversification of crops, cultivar types or animal breeds to minimize the risk of production losses due to changing climatic conditions or climate-driven pest or disease outbreaks (Burnham and Ma, 2015; Lin, 2011), among others. At the landscape scale, examples of EbA include the conservation or restoration of riparian forests to maintain stream flow under changing rainfall conditions (e.g., Capon et al., 2013), and the conservation of forests in upland areas to help prevent erosion and landslides due to extreme weather events (Locatelli et al., 2011).

Ecosystem-based Adaptation has been proposed as a particularly important adaptation strategy for smallholder farmers who often lack the resources and capacity to access other adaptation options, such as the adoption of new technologies that require external inputs (e.g., improved seed varieties, irrigation systems or increased fertilizer and pesticide use) or participation in farm insurance (Vignola et al., 2015). However, despite growing interest in the potential role of EbA in helping smallholder farmers adapt to climate change, there is still limited information on the use of EbA by smallholder farmers. According to a recent global review of smallholder responses to climate change (Burnham and Ma, 2015), many smallholder farmers are adopting environmental management practices in response to climate change, but more systematic and detailed information is needed on the specific practices farmers adopt and why. Information is lacking on what EbA practices farmers are using, how the use of EbA practices varies across farms and landscapes and what factors influence EbA use. While there have been previous characterizations of individual agroecological practices, such as shade trees, live fences and dispersed trees (e.g., Harvey et al., 2005, 2011; Haggar et al., 2015; Hellin et al., 1999), that could help farmers improve the sustainability of their farms and improve farm resiliency to climate change, there have been no systematic studies that have considered the full range of EbA practices present on smallholder farms. In addition, while there have been studies examining the factors associated with the use of individual agricultural practices (e.g., Nkamleu and Manyong, 2005; Wall, 2007), there has been no efforts to understand which factors are correlated with the use of multiple EbA practices at the farm level.

Understanding the potential use of EbA by smallholder farmers is particularly relevant to Central America, a region with an estimated 2.3 million smallholder farmers (PRESANCA and FAO, 2011) who cultivate marginal, steep lands and depend on agriculture for both food security and income generation (Hellin and Schrader, 2003; Tucker et al., 2010). As in other regions, smallholder farmers in Central America are highly vulnerable to climate change and face a range of climatic threats, including higher temperatures, more variable rainfall, and more frequent and more intense extreme weather events (Baca et al., 2014; Hannah et al., 2017). Changes in climatic conditions are expected to lead to significant changes in water availability (Imbach et al., 2015), increased pest and disease outbreaks (Avelino et al., 2015), and reduced crop productivity of key smallholder crops, such as coffee, maize and beans (Baca et al., 2014; Jones and Thornton, 2003). Climate change also threatens food security and farmer wellbeing across the region (Bacon et al., 2017; Hannah et al., 2017). Adaptation strategies that can help build resiliency of smallholder farmers to climate change are urgently needed across Central America (Schroth et al., 2009), yet information on appropriate adaptation strategies (and the potential role for EbA) for smallholder farmers is scant and insufficient to guide adaptation policies and strategies (Donatti et al., 2017).

We explored the potential role of EbA in helping smallholder farmers adapt to climate change by conducting participatory mapping and field surveys of EbA practices in six different smallholder farming landscapes in Central America. The specific objectives of our work were: 1) to document the prevalence of EbA practices on smallholder farms and characterize how these practices are implemented, and 2) explore which biophysical and socioeconomic factors are correlated with the presence of individual EbA practices. Our study provides novel information on the use of EbA practices by smallholder farmers and provides important insights into the factors that are associated with EbA use and the potential for EbA systems to help smallholder farmers adapt to climate change. These issues are of international importance given the estimated more than 500 million smallholder farms worldwide, the importance of smallholder farmers for global food security, and their high vulnerability to climate change (Graeub et al., 2016; Morton, 2007).

2. Methods

We characterized EbA practices on smallholder farms in 6 Central American landscapes (Turrialba and Los Santos in Costa Rica, Choluteca and Yoro in Honduras, and Chiquimula and Acatenango in Guatemala, Fig. 1), that were typical of smallholder farmer landscapes in the region. We selected landscapes that a) were dominated by smallholder farming systems, b) had coffee and/or basic grain production (beans and maize) as the predominant agricultural land use, and c) had farming communities with low adaptive capacity to climate change. We focused our study on smallholder farmers who had either coffee or basic grain production as these are the two most common types of smallholder systems in the region (Baca et al., 2014). We characterized landscapes as having low adaptive capacity using expert mapping interviews, validation workshops and expert on-line surveys, in which experts from the region characterized landscapes on the basis of 20 variables (representing natural, human, social, physical and financial capital) that contributed to farmer adaptive capacity. Additional details on the methodology and analysis are provided in Holland et al. (2017). Of the six selected landscapes, the Turrialba and Los Santos landscapes are dominated by coffee production, Choluteca is dominated by basic grain production, while the remaining landscapes (Yoro, Acatenango and Chiquimula) include a mix of coffee and basic grain production. Key characteristics of each of the landscapes can be found in Table 1.

In each landscape, we had previously conducted an extensive household survey of randomly-chosen smallholder farms, using a rigorous sampling frame. In the Costa Rican landscapes, we selected farmers randomly from an existing list of coffee farms. In the Guatemalan and Honduran landscapes, we generated a sampling frame by using remote sensing imagery to detect household roofs and then randomly sampling households from this list of potential farms. In total, we sampled 860 randomly-selected farmers (115–155 farmers per landscape). The household survey included information on farm, farmer and household characteristics, and farmer-reported presence of EbA on farms, among other aspects. In each landscape, we used information on the number of EbA practices reported by farmers in the household survey to stratify the farmers in each landscape into two groups (a group with a relatively ‘high’ number of EbA practices, and a group with a relatively ‘low’ number of EbA practices) based on the frequency of the number of reported EbA practices per farm. We then randomly selected 25 farmers from both the ‘high’ and ‘low’ groups for field work (for a total of 50 farmers per landscape), to ensure that our field survey covered the diversity of farm types present in each landscape. Our total

Fig. 1. Location of six agricultural landscapes in Central America in which the use of EbA practices by smallholder farmers was characterized.

sample size was 300 farms (50 per landscape X 6 landscapes).

To characterize the use of EbA in each of the 300 selected farms, we first used participatory mapping methods with the farmer to locate individual plots on the farm and characterize their land use (e.g., crop fields, pastures, fallows, forested areas, water bodies, etc.). We then asked farmers to identify which EbA practices they had on individual plots and to indicate on the map where each practice was applied, so that we could visit these areas and characterize the practices through field work. Specifically, we recorded the presence/absence of 12 EbA practices: the use of shade in coffee plots, dispersed trees in maize or bean fields, live fences, windbreaks, home gardens, terraces, contour planting, use of crop cover, fallows, riparian forests, forest patches and forest plantations. This list of EbA practices was based on an extensive literature review of practices commonly used by smallholder basic grain (maize and beans) and coffee farmers (Bautista-Solís et al., 2014).

For each EbA practice present on the farm, we collected detailed information on how the practice was implemented. For forests, riparian forests, home gardens, windbreaks, forest plantations and fallows, we measured the area of all plots and calculated the total area under this practice at the farm level. To characterize the use of EbA practices within coffee plots, we randomly selected up to three coffee plots per farm. Within each coffee plot, we established an area of 20 × 50 m (1000 m^2) in the center of the plot and measured the number, species and mean diameter at breast height (dbh) of all shade trees. We similarly randomly selected up to three plots of basic grains per farm and established an area of 20 × 50 m (1000 m^2) in the center of the plot to characterize the number, species and dbh of dispersed trees in the plot. Finally, for live fences, we randomly selected up to 6 live fences per farm and registered the number of trees, tree species, and tree diameters at breast height of all trees with dbh > 5 cm in a randomly-chosen 100 m length of the fence. For all three practices (shade trees in coffee, dispersed trees in maize fields and live fences), we summarized information in terms of the mean tree species per plot, mean dbh per plot, and mean tree density (trees per ha). We also recorded whether the farmer used cover crops, terraces and contour planting in either coffee or basic grain fields. All data were collected in the field using tablets, programmed with SurveyCTO software, a product that captures, stores and processes data collected during structured interviews and field work (www.surveycto.com). Field work was conducted from July 2014 to June 2015.

We used descriptive statistics to characterize the prevalence of EbA practices across farms and landscapes, calculating the percentage of farms with individual EbA practices and the total number of EbA practices per farm. We explored the relationships of biophysical factors (such as farm size, field size, presence of water bodies, etc.) and socioeconomic factors (such as farmer age, years of farming experience, education, gender, family size and farmer access to technical support and training) with both the presence of individual EbA practices and the characteristics of these practices, as these factors have been shown to be important determinants of the adoption of agroecological practices elsewhere (e.g., Akinnifesi et al., 2010; Thangata and Alavalapati, 2003). Specifically, we used 7 biophysical factors and 9 socioeconomic variables as explanatory variables, and 24 EbA variables as response variables (including 10 variables related to the presence or absence of individual EbA practices, and 14 variables reflecting the characteristics of individual EbA practices). Table 2 provides details on the biophysical, socioeconomic and EbA variables included in the analysis.

We conducted simultaneous regression or classification trees analyses for each of the quantitative or qualitative response variables, respectively, using the RandomForest algorithm. RandomForest is a non-parametric algorithm that identifies a combination of variables that maximize the relationships between each of the explanatory variables and the response variables by dividing the sample into homogenous groups in a random way (Liaw and Wiener, 2002). The method avoids problems of collinearity among explanatory variables and makes it possible to identify nonlinear relationships. All quantitative EbA variables were standardized using z-scoring prior to regression tree analysis. We determined the relative importance of each explanatory variable for each EbA response variable using the mean decrease in accuracy for regression trees and the mean decrease in Gini index in the classification trees, and obtained p values for these metrics by running 1000 permutations using rfPermute (Archer, 2016).

We used principle components analysis (PCA) using the expected values obtained from the regression trees and with the probability values obtained from the classification tree analysis for each EbA variable to summarize the relationships among all variables. On the resulting PCA, we estimated the covariance matrix between the two major axes (principle components) and the predictor variables, so that we could graphically illustrate the associations between socioeconomic

Table 1
Characteristics of the agricultural landscapes and smallholder farms in Central America where EbA practices were characterized. Data on farm and plot size come from the 50 farmers surveyed per landscape. Letters associated with means indicate statistical differences across landscapes, based on ANOVA ($p < 0.05$).

Characteristics		Turrialba, Costa Rica	Los Santos, Costa Rica	Acatenango, Guatemala	Chiquimula, Guatemala	Choluteca Honduras	Yoro, Honduras
Landscape characteristics	Holdridge life zone	Premontane Tropical Wet Forest Premontane Rainforest	Lower Montane Wet Forest Premontane Rainforest	Subtropical Wet Forest	Subtropical Moist Forest	Tropical Dry Forest	Subtropical Wet Forest Subtropical Moist forest
	Municipalities included in survey	Turrialba	Dota, Tarrazú, León Cortés	Acatenango, Alotenango, San Pedro Yepocapa	Quetzaltepeque, San Jacinto, San Juan Ermita	El Triunfo, Concepción de María	Yoro, Yorito, Victoria
	Total area (ha)	158,800	82,000	42,600	39,600	47,500	325,900
Sample size	Total # of farmers surveyed	50	50	50	50	50	50
	# (and%) of farmers who only had coffee production	50 (100%)	50 (100%)	35 (70%)	3 (6%)	0	2 (4%)
	# (and%) of farmers who only had basic grain production	0	0	8 (16%)	30 (60%)	50 (100%)	21 (42%)
	# (and%) of farmers who had both coffee and basic grain production	0	0	7 (14%)	17 (34%)	0	27 (50%)
Farm characteristics	Main farming system	Coffee	Coffee	Coffee and basic grains	Coffee and basic grains	Basic grains	Coffee
	Mean farm size (ha) of all farms (± SE) (n = 50/landscape)	3.07 ± 2.92 b	18.97 ± 2.92 a	2.66 ± 2.92 b	1.94 ± 2.95 b	3.28 ± 2.92 b	4.16 ± 2.92 b
	Mean farm area (ha) under coffee (± SE)	1.13 ± 0.27 b (n = 50)	2.62 ± 0.27 a (n = 50)	0.11 ± 0.30 c (n = 42)	0.24 ± 0.43 bc (n = 20)	–	0.85 ± 0.36 bc (n = 29)
	Mean area (ha) under beans or maize production (± SE)	–	–	0.50 ± 0.19 ab (*n*-14)	0.57 ± 0.09 ab (n = 47)	0.49 ± 0.08 b (n = 50)	0.80 ± 0.09 a (n = 48)
	Mean family size of smallholder farmers (± SE)	3.28 ± 0.30 b	3.60 ± 0.30 b	5.86 ± 0.30 a	5.18 ± 0.30 a	5.36 ± 0.30 a	5.82 ± 0.30 a
Land tenure	Own all land they cultivate	100%	100%	70%	44%	27%	68%
	Own some land, and rent additional land	0%	0%	12%	30%	53%	32%
	Rent land	0%	0%	18%	26%	20%)	0%

Table 2
Summary of the variables used to explore relationships between biophysical and socioeconomic factors and the presence or characteristics of EbA practices on smallholder farms in Central America.

Type of variable	Variable name	Variable type (ordinal, continuous or binary)	Explanation of variable
Biophysical explanatory variables	Landscape	O	Landscape (Turrialba, Santos, Acatenango, Chiquimula, Choluteca, Yoro)
	Farm type	O	Farm type (coffee only, maize only, mixed)
	Farm size	C	Total farm size (ha)
	Distance	C	Distance from house to farm (km)
	Water source	B	Presence of stream or river on farm (yes/no)
	Coffee area	C	Mean size of coffee plots (ha)
	Grain area	C	Mean size of grain fields (ha)
Socioeconomic explanatory variables	Age	C	Farmer age (years)
	Gender	B	Farmer gender (male/female)
	Education	C	Farmer years of education (yrs)
	Experience	C	Farmer years of experience (yrs)
	Family size	C	Family size (number of household members living on farm)
	Tenure	O	Land tenure (own all land they cultivate, own land and rent, rent only)
	Training	B	participated in training events during the last two years? (yes, no)
	Tech support	B	Received technical advice from extension agents during last two years (yes/no)
EbA presence variables[a]	Contour planting	B	Presence of contour planting on farm (yes/no)
	Cover crops	B	Presence of cover crops on farm (yes/no)
	Shade trees (coffee)	B	Presence of dispersed trees in coffee plots
	Dispersed trees (grains)	B	Presence of dispersed trees in basic grain plots
	Live fences	B	Presence of live fences on farm (yes/no)
	Home gardens	B	Presence of home garden (yes/no)
	Fallows	B	Presence of fallows on farm (yes/no)
	Forests	B	Presence of forest fragment on farm (yes/no)
	Riparian forests	B	Presence of riparian forests on farm (yes/no)
	Terraces	B	Presence of terraces on farm (yes/no)
	# EbA practices	C	# of EbA practices on the farm
EbA characteristics[b]	Tree spp (grains)	B	Mean tree species richness in basic grain fields
	Tree density (grains)	C	Mean tree density in basic grain fields (trees/ha)
	Tree dbh (grains)	C	Mean tree diameter at breast height of trees in grain fields (cm)
	Tree spp (coffee)	C	Mean tree species richness in coffee fields
	Tree density (coffee)	C	Mean tree density in coffee fields (trees/ha)
	Tree dbh (coffee)	C	Mean tree diameter at breast height of trees in coffee fields (cm)
	Home garden area	C	Area under home garden (ha)
	Tree spp (live fences)	C	Mean tree species richness per live fence
	Tree density (live fences)	C	Mean tree density (trees per km) of live fences
	Tree dbh (live fences)	C	Mean tree diameter at breast height of trees in live fences (cm)
	Fallow area	C	Area under fallow (ha)
	Forest area	C	Area under forest (ha)
	Riparian area	C	Area under riparian forest (ha)

[a] Presence/absence variables were used in classification tree analyses (due to binary nature of variables).
[b] EbA characteristics variables were used in the regression tree analyses.

biophysical and EbA variables. All analyses were done using the statistical package InfoStat (Di Rienzo et al., 2016), with the R package (R Core Team, 2015) using the library randomForest (Liaw and Wiener, 2002).

3. Results

We characterized 300 smallholder farms, measuring a total of 292 coffee plots (including measurements of 7665 shade trees), 268 maize plots (including 1685 dispersed trees), 206 live fence plots (including 6475 trees), 84 forest fragments (501.7 ha), 27 riparian forests (8.46 ha), 88 fallows (61.6 ha), and 3 forest plantations (0.6 ha). Of the 300 smallholder farms surveyed, 140 were smallholder coffee farms, 109 were basic grain farms, and 51 were mixed farms with both coffee and basic grain production (Table 1). The overall mean size of farms was 5.69 ± 1.23 ha, and farm families averaged 4.85 ± 0.13 members. The mean area of coffee plots on farms was 1.16 ± 0.15 ha, while the mean area planted under basic grain was 0.61 ± 0.05 ha. Of the farmers surveyed, 68% owned all of the land they cultivated, 21% owned some of the land they cultivated but also rented land, and 10% cultivated land that was rented.

3.1. Prevalence and characteristics of EbA practices in smallholder farms

Smallholder farmers had an average of 3.78 ± 0.09 EbA practices per farm, with a range from 1 to 8 practices per farm. There was a lot of variation in prevalence and characteristics of individual EbA practices across the 300 farms (Table 3). The most common EbA practice, across all farms, was the use of live fences, which were found on 68% of all farms. Live fences typically had low species richness, high tree densities, and consisted of trees with small diameters. Small home gardens were also common, occurring on 61% of surveyed farms and covering an average of 733 m^2. The use of shade trees was common in coffee plots (occurring on 94% of coffee farms), with high tree densities (mean of 274 per ha), low species richness (mean of 6.8 species/plot) and medium-sized trees (mean dbh of 16.1 cm). In basic grain fields, 73% of the fields had dispersed trees. Tree densities and species richness were lower in basic grain fields than in coffee fields, but trees were of a similar diameter size. Other EbA practices were much less common on smallholder farms. For example, just over 20% of the farms had forest patches, used fallows or used terraces. Riparian forests were present on 9% of farms. The least common practices were the use of cover crops (present on only 3% of farms), windbreaks (1%) and forest plantations (1%).

Table 3
A summary of the prevalence and characteristics of EbA practices on 300 smallholder farms in Central America, in decreasing order of abundance.

EbA practice	Prevalence of EbA practice		Characteristics		
	N (farms)	# (%) of farms	n	Variable	Mean ± SE
Shade trees in coffee plots	191	180 (94%)	282 plots	tree density (trees/ha)	274.33 ± 13.85
			282 plots	species richness (per plot)	6.36 ± 0.36
			7665 trees	tree diameter (dbh) cm	16.13 ± 0.12
Dispersed trees in maize fields	155	114 (73%)	1686 trees	tree density (trees/ha)	119.96 ± 8.75
			268 plots	species richness (per plot)	4.41 ± 0.26
			268 plots	tree diameter (dbh) cm	16.17 ± 0.31
Live fences	300	206 (68%)	553 plots	tree density (trees per km)	372.90 ± 38.58
			553 plots	species richness (per plot)	4.39 ± 0.25
			6475 trees	tree diameter (dbh) cm	9.87 ± 0.11
Home gardens	300	184 (61%)	6	area (ha)	0.07 ± 0.01
Contour planting	300	177 (59%)	–	–	–
Forests	300	71 (23%)	71	area (ha)	6.19 ± 2.63
Terraces	300	69 (23%)	–	–	–
Fallows	300	68 (22%)	68	area (ha)	0.64 ± 0.09
Riparian forests	300	27 (9%)	27	area (ha)	0.31 ± 0.08
Cover crops	300	10 (3%)	–	–	–
Forest plantations	300	3 (1%)	3	area (ha)	0.19 ± 0.10
Windbreaks	300	3 (1%)	3	area (ha)	0.04 ± 0.02

3.2. Factors associated with the presence of EbA practices on smallholder farms

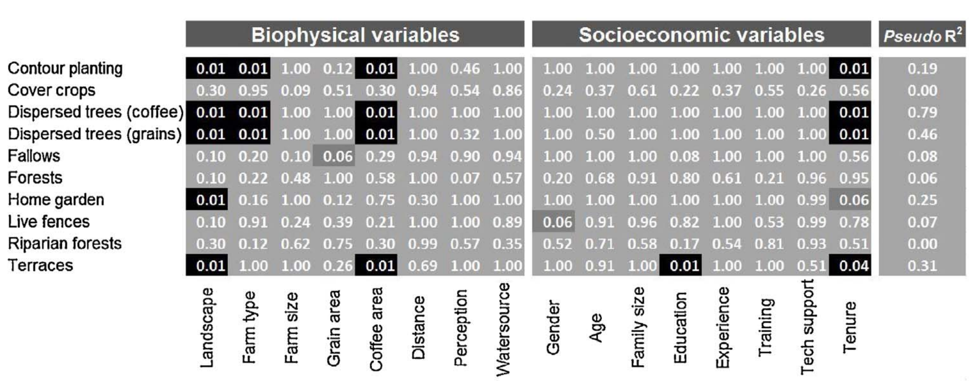
According to the classification tree analysis (Fig. 2), the presence of five EbA practices (contour planting, shade trees in coffee, dispersed trees in grain fields, home gardens and terraces) was significantly associated with biophysical and socioeconomic variables. In contrast, the presence of the remaining five EbA practices (use of cover crops, fallows, forests, live fences, and riparian forests) was not significantly explained by biophysical and socioeconomic variables.

The individual biophysical and socioeconomic variables influencing the presence of EbA practices varied across practices (Fig. 2). For example, the use of contour planting was significantly associated with the individual landscapes, farm type, the area under coffee, and land tenure. As shown in the graph of the PCA (Fig. 3), contour planting was more common on coffee farms, farms with larger coffee plots, landscapes dominated by coffee production, and on farms with secure land tenure. The use of dispersed trees in coffee plots was most common in the farms and landscapes where coffee is a major land use, in farms with larger coffee plots, and where land tenure is secure (Figs. 2 and 3). Conversely, the presence of dispersed trees in maize was associated with landscapes dominated by basic grain production (Figs. 2 and 3), and in basic grain farms, many of which are of farmers who lack land tenure. The presence of terraces was more common on coffee farms, landscapes with coffee production, farms with larger coffee plots, farms with farmers who have higher education, and farms with land tenure (Figs. 2 and 3). Finally, the presence of home gardens was associated with landscape type, with home gardens being less common in the Guatemalan landscapes than the others studied (Figs. 2 and 3).

The overall number of EbA practices per farm was significantly associated with landscape, farm type, area under coffee, farmer age and farmer experience (overall R^2 value of 0.38, Fig. 4). The number of EbA practices per farm was higher in coffee farms and mixed farms than in basic grain farms, and higher in certain landscapes (Los Santos, Yoro) than in others (Fig. 5). The number of EbA practices per farm was also positively associated with farmer experience and farmer age; that is, older and more experienced farmers tended to have more EbA practices on their farms than younger, less experienced farmers (Fig. 5).

3.3. Factors affecting the characteristics of EbA implementation

There were also significant relationships between the characteristics of EbA practices on smallholder farms and the biophysical and socioeconomic variables. According to the regression tree analysis, seven of the 14 variables describing the characteristics of EbA practices were significantly associated with biophysical and socioeconomic variables (Fig. 4). These variables included the mean tree species richness, tree density and tree dbh of dispersed in grain fields, the mean tree species richness, density and tree diameters of shade trees in coffee fields, and the total number of EbA practices per farm.



	Biophysical variables								Socioeconomic variables								Pseudo R^2
	Landscape	Farm type	Farm size	Grain area	Coffee area	Distance	Perception	Watersource	Gender	Age	Family size	Education	Experience	Training	Tech support	Tenure	
Contour planting	0.01	0.01	1.00	0.12	0.01	1.00	0.46	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.01	0.19
Cover crops	0.30	0.95	0.09	0.51	0.30	0.94	0.54	0.86	0.24	0.37	0.61	0.22	0.37	0.55	0.26	0.56	0.00
Dispersed trees (coffee)	0.01	0.01	1.00	1.00	0.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.01	0.79
Dispersed trees (grains)	0.01	0.01	1.00	1.00	0.01	1.00	0.32	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	0.01	0.46
Fallows	0.10	0.20	0.10	0.06	0.29	0.94	0.90	0.94	1.00	1.00	1.00	0.08	1.00	1.00	1.00	0.56	0.08
Forests	0.10	0.22	0.48	1.00	0.58	1.00	0.07	0.57	0.20	0.68	0.91	0.80	0.61	0.21	0.96	0.95	0.06
Home garden	0.01	0.16	1.00	0.12	0.75	0.30	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.06	0.25
Live fences	0.10	0.91	0.24	0.39	0.21	1.00	1.00	0.89	0.06	0.91	0.96	0.82	1.00	0.53	0.99	0.78	0.07
Riparian forests	0.30	0.12	0.62	0.75	0.30	0.99	0.57	0.35	0.52	0.71	0.58	0.17	0.54	0.81	0.93	0.51	0.00
Terraces	0.01	1.00	1.00	0.26	0.01	0.69	1.00	1.00	1.00	0.91	1.00	0.01	1.00	1.00	0.51	0.04	0.31

Fig. 2. Matrix showing the significance (p value) for each of the explanatory variables in explaining the presence or absence of individual EbA practices, based on the adjusted classification trees and a pseudo R^2. Shading indicates the level of significance, with black indicating p values < 0.05, and dark grey indicating p values between 0.05 and 0.10.

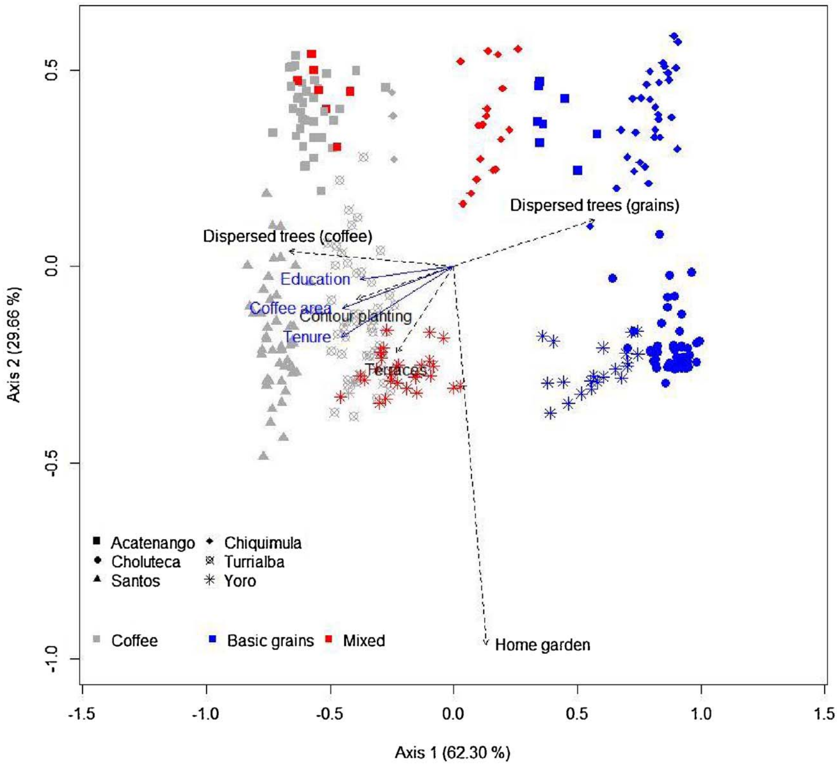


Fig. 3. Relationships between socioeconomic and biophysical explanatory variables (shown in blue text) and the presence of individual EbA practices (shown in black text) on smallholder farms in Central America (n = 300 farms), based on the PCA analysis of the classification tree outputs. Symbol colors represent different types of farms (coffee, basic grains and mixed farms), while symbol shapes represent the different landscapes in which EbA practices were surveyed.

The biophysical and socioeconomic variables affecting the characteristics of EbA practices varied depending on the specific practice. Some of these relationships simply reflected differences in the main land use. For example, the characteristics of dispersed trees (e.g., tree species richness, density and mean dbh of trees) in basic grain fields were explained by the farm type, the landscape, the mean area under coffee, and farmer experience (Fig. 4). As shown in Fig. 5, the tree species richness, density and diameter sizes of trees in maize fields were positively associated with basic grain and mixed farms, but negatively associated with farmer experience. Similarly, the species richness, density and mean dbh of trees used as shade in coffee plantations were all significantly associated with landscape, farm type and mean area under coffee, with the greater species richness, density and dbh of trees in landscapes dominated by coffee and mixed farming systems, and in farms with larger coffee plantations (Fig. 5).

4. Discussion

Our study provides the first detailed analysis on the prevalence and characteristics of EbA practices implemented by smallholder farmers and helps fill a gap in our understanding of the use of EbA by smallholder farmers. It also provides key information on some of the factors associated with the use of EbA practices by smallholder farmers, which can be helpful for policy makers and practitioners interested in scaling up EbA implementation across the region (Donatti et al., 2017).

	Biophysical variables								Socioeconomic variables								R^2
	Landscape	Farm type	Farm size	Grain area	Coffee area	Distance	Perception	Watersource	Gender	Age	Family size	Education	Experience	Training	Tech support	Tenure	
Tree spp (grains)	0.89	0.01	1.00	1.00	0.01	1.00	0.62	1.00	0.34	0.42	1.00	1.00	0.01	0.72	1.00	1.00	0.53
Treed density (grains)	0.10	0.01	1.00	1.00	0.01	1.00	1.00	0.63	0.74	1.00	0.59	1.00	0.01	1.00	0.06	1.00	0.38
Tree dbh (grains)	0.09	0.01	1.00	1.00	0.01	1.00	0.37	1.00	0.52	0.92	0.28	0.99	0.04	1.00	1.00	1.00	0.40
Tree spp (coffee)	0.01	0.01	0.74	0.65	0.01	0.97	0.22	1.00	0.57	0.41	0.96	1.00	1.00	0.59	1.00	1.00	0.46
Tree density (coffee)	0.01	0.01	1.00	1.00	0.01	1.00	1.00	0.68	0.20	1.00	1.00	1.00	1.00	0.97	0.47	0.58	0.43
Tree dbh (coffee)	0.03	0.01	1.00	1.00	0.01	1.00	1.00	1.00	0.37	0.12	0.80	1.00	1.00	1.00	0.97	1.00	0.50
Home garden area	0.19	0.22	0.12	0.96	0.13	0.98	0.46	0.26	0.76	0.50	0.31	0.95	0.44	0.95	0.30	0.90	0.02
Tree spp (live fences)	0.20	0.10	0.91	0.96	0.10	0.36	1.00	0.14	0.66	0.99	0.88	0.99	0.97	0.99	0.85	0.12	0.10
Tree density (live fences)	0.50	0.20	0.94	0.11	0.61	0.77	0.43	0.57	0.38	0.59	0.38	0.21	0.11	0.89	0.64	0.11	0.02
Tree dbh (live fences)	0.91	0.13	0.85	0.77	0.07	0.57	0.90	0.92	0.61	0.10	0.78	0.45	1.00	0.11	0.97	1.00	0.10
Fallow area	0.21	0.85	0.39	0.60	0.13	0.54	0.75	0.80	0.23	0.13	0.17	0.74	0.72	0.51	0.30	0.49	0.00
Forest area	0.11	0.79	1.00	0.39	0.35	0.48	0.30	0.94	0.68	0.60	0.22	0.97	0.67	0.19	0.29	0.87	0.00
Riparian area	0.77	0.49	0.17	0.29	0.13	0.67	0.63	0.43	0.79	0.16	0.83	0.39	0.14	0.96	0.96	0.29	0.00
#EbA practices	0.01	0.01	0.40	0.28	0.01	1.00	1.00	0.97	0.29	0.01	1.00	1.00	0.01	1.00	0.92	1.00	0.38

Explanatory variable

Fig. 4. Matrix showing the significant (p value based on the metric of importance) of each of the explanatory variables in explaining individual EbA characteristics, based on the adjusted regression tree analysis and the coefficients of determination. Shading indicates the level of significance, with black indicating p values < 0.05, and dark grey indicating p values between 0.05 and 0.10.

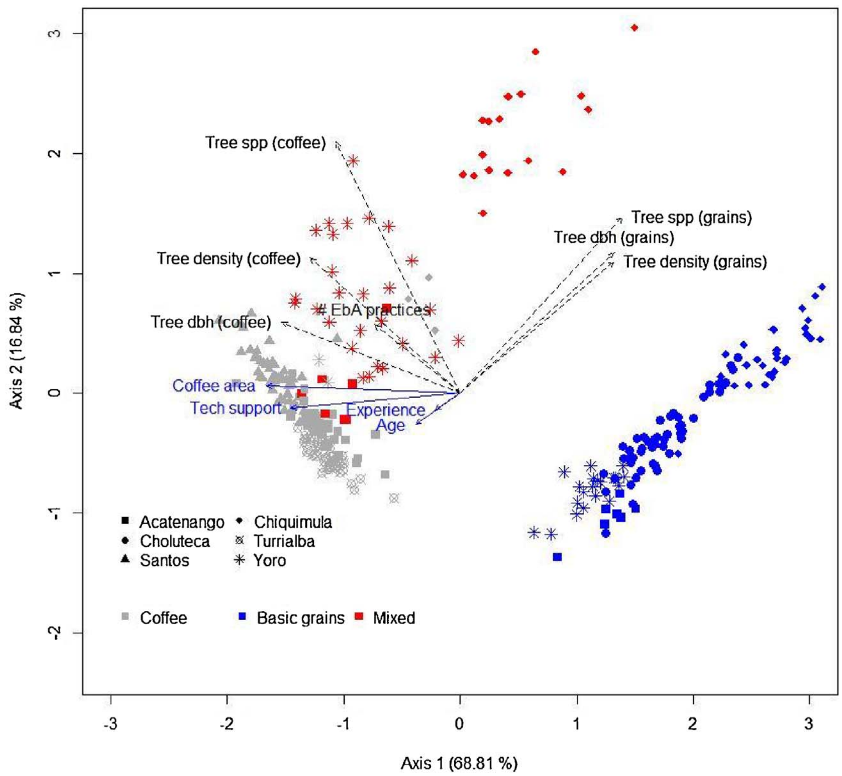


Fig. 5. Relationships between socioeconomic and biophysical explanatory variables (shown in blue text) and the characteristics of individual EbA practices (shown in black text) on smallholder farms in Central America (n = 300 farms). Symbol colors represent different types of farms (coffee, basic grains and mixed farms), while symbol shapes represent the different landscapes in which EbA practices were surveyed.

4.1. Prevalence of EbA practices on smallholder farms

Overall, our study indicates that many smallholder coffee and basic grain farmers in Central America are using EbA practices on their farms, although there is significant variation in the prevalence of individual practices. The smallholder farmers we surveyed had an average of 3.8 EbA practices per farm, with the most common practices being the use of live fences, home gardens, dispersed trees in grain fields and shade in coffee plantations.

Our findings are likely generalizable to the smallholder coffee and basic grain landscapes that dominate much of Central America, as the landscapes we surveyed were selected to be representative of the region and cover the main biophysical conditions present (ranging from tropical dry forests to tropical wet forests). In addition, some of the EbA practices have been previously documented in the region with similar characteristics to those reported here. For example, the use of shade in coffee plantations has been well-documented in Central America and the tree densities, species richness and diameter sizes of trees in coffee plantations in our landscapes fall within the ranges reported elsewhere in the region (e.g., Haggar et al., 2015; Valencia et al., 2014). The abundance and characteristics of live fences on the smallholder coffee and basic grain farms surveyed are similar to those reported from cattle landscapes in the region (Harvey et al., 2005), though, to our knowledge, our study is the first to systematically document the use of live fences in smallholder coffee and maize farms in the region. For other practices, such as the use of dispersed trees in maize and bean fields, the conservation of forest fragments and riparian forests, the use of fallows, the use of cover crops, and the use of windbreaks, it is more difficult to know whether our results are representative of the region, given the scarce information on these practices in the region.

The prevalence of EbA practices and the high abundance of certain EbA practices (e.g., shade trees in coffee, live fences, home gardens, dispersed trees in maize fields) on smallholder farms in the region likely reflects a combination of factors, beyond solely the adaptation benefits of these practices. First, many of these practices that are now recognized as EbA are agroecological practices that local populations have used for decades (e.g., Altieri et al., 2012). For example, the use of a diverse shade canopy in coffee systems is a common practice across Central America (Jha et al., 2011), as is the integration of dispersed trees in maize fields in Honduras and Guatemala (Hellin et al., 1999).

Second, many of the EbA practices present on smallholder farms have been widely promoted by agricultural extension services, farmer cooperatives, and NGOs for their ability to improve farm sustainability, support agricultural production and improve farmer livelihoods. For example, the use of shade in coffee systems has been promoted to diversify farm production and income generation, maintain ecosystem services, conserve biodiversity and enhance farm resiliency (e.g., Allinne et al., 2016; Jha et al., 2011; Schroth et al., 2009). The planting of live fences has been encouraged as a cost-effective means of dividing fields, creating barriers to animal movement, and providing animal fodder, firewood, timber and fruits (Harvey et al., 2005). Other EbA practices have been widely encouraged, but are still relatively uncommon on smallholder farmers. For example, cover crops have also been widely promoted in the region but are rarely found on smallholder farms, perhaps due to the additional labor required to sow the crops, the cost of cover crop seeds, and the need to change farm management practices (Erenstein, 2003; Hellin and Ridaura-López, 2016). The infrequent use of other EbA practices- such as the conservation of forest patches or fallows or windbreaks- by smallholder farmers probably reflects the fact that these practices take up significant land and therefore represent a significant opportunity cost to farmers with small landholdings (Current, 1995; Michalski et al., 2010).

Finally, the prevalence of EbA practices on smallholder farms also likely reflects the fact that many of these practices are now increasingly being promoted specifically for their ability to reduce the effects of climate change. For example, the use of shade in coffee plantations has been demonstrated to buffer maximum and minimum air and leaf temperatures within the coffee plantation (Lin, 2007; Siles et al., 2010), reduce the impact of heavy rainfall associated with hurricanes (Cannavo et al., 2011), and reduce the frequency of landslides due to the stabilizing effects of the roots of shade trees (Philpott et al., 2008), though the specific impacts of these measures depend on shade composition and plantation management. Similarly, there is growing recognition that the use of soil conservation methods and live fences can help farm adaptation to climate change by increasing soil water infiltration, retaining soil water moistures, reducing soil erosion and enhancing the overall resiliency of farms to extreme weather events such as hurricanes (e.g., Erenstein, 2003; Holt-Giménez, 2002; Pineda Rizo and Aguilera Ruíz, 1999). As the impacts of climate change are becoming more pronounced in the region (Hannah et al., 2017), farmer organizations, NGOs, and agricultural technicians are now championing the use of these EbA practices to help farmers reduce the impacts of rising temperature and irregular rainfall on their farming systems, and deal with the increasing intensity and frequency of extreme weather events (such as strong rainfall events, heavy winds, or severe droughts; e.g., Lin, 2007; Schroth et al., 2009). For example, in Choluteca, Honduras, NGOs such as ADETRIUNF (Asociación de Desarrollo Triunfeño) and ACESH (Asociación de Comités Ecológicos del Sur) are training smallholder farmers on the use of agroecological practices (including many of the EbA practices reported here), while in the Los Santos region of Costa Rica, many of the local coffee cooperatives are promoting these practices to enhance the overall resiliency of coffee systems. The use of EbA on farms therefore probably reflects both past and ongoing efforts to promote more sustainable and climate-resilient practices, and will likely increase as countries begin to more aggressively implement their adaptation plans for the agricultural sector.

4.2. Factors affecting the prevalence and characteristics of EbA practices

Our analysis indicates that certain biophysical and socioeconomic factors were closely associated with the number of EbA practices present, the presence of specific EbA practices, and the characteristics of these practices. The biophysical variables that were related to EbA variables included the mean size of coffee plots, farm types, and the landscape, while the socioeconomic variables that were associated with EbA practices included farmer age, farmer experience and land tenure.

Several of the biophysical and socioeconomic factors that were identified as influencing the use of EbA or the way in which EbA practices are implemented, have been highlighted as important in determining farmer management practices in other regions. The size of coffee farms can be an important determinant of how the coffee plantations are managed. For example, a study of coffee farmers in Kenya (Ithinji, 2011) found that coffee farmers with larger farms were more likely to have open coffee than shade coffee. In contrast, in our study, smallholder farmers with larger coffee fields were more likely to have shade trees, to have greater tree densities and larger trees, and more likely to use contour planting than those with smaller coffee plots. Our results could indicate that these farmers are more actively protecting their coffee plots with a longer-term view of coffee activity than those who have less coffee under production or alternatively, that these farmers are using shade to reduce inputs (herbicide and fertilizer) and related costs which are greater in larger coffee fields, however additional information is needed to better understand these relationships. The age and experience of farmers has also been highlighted as a key determinant of farm management practices, with higher education being positively correlated with use of adaptation strategies by farmers in Tanzania (Below et al., 2012) and Ethiopia (Deressa et al., 2010) and farmer age being a key determinant of the adoption of agroforestry practices in Malawi (Thangata and Alavalapti, 2003) and in Uganda (Hisali et al., 2011). In our study, both farmer age and experience were similarly positively associated with the total number of EbA practices on farms, suggesting that experience may lead farmers to adopt more sustainable practices. Farmer education levels have been found to influence adoption of farm management practices and the adaptation of farming practices in response to climate change elsewhere (e.g., Knowler and Bradshaw, 2006). In our study, farmers with greater education were more likely to use terraces than those with lower education levels. Finally, land tenure has been highlighted as an important factor influencing the adoption of several EbA practices, including the use of cover crops, forest conservation, and tree planting (e.g., Hellin and Schrader, 2003; Hisali et al., 2011; Wall, 2007), because many of these practices may only yield benefits after several years of implementation. In our study, farmers with secure land tenure were more likely to have shade trees in coffee plantations and to use terracing and contour planting than those lacking tenure, suggesting that those farmers who own the land are more likely to commit to practices that are long-term investments and yield long-term benefits.

It is interesting to note, however, that some biophysical and socioeconomic factors that we anticipated would be important in affecting the use of EbA were not associated with either the number of EbA practices, the specific EbA practices used or how they were implemented. For example, we anticipated that the presence of water (rivers, streams or ponds) on a farm might affect EbA use, particularly the conservation of forests or riparian forests to protect water sources, as has been found elsewhere (Michalski et al., 2010). However, in our study the presence of water on the farm was not associated with either the number of EbA practices or the presence of specific EbA practices. In most Central American countries, the protection of water sources or rivers is regulated by law (e.g., Asamblea Legislativa, 1996). However, in many remote rural regions, the influence of government laws is quite limited and the regulations regarding riparian forest protection may not be well-known or may be ignored by smallholder farmers who have limited land area and need to farm the land adjacent to streams. Farmer decision-making about forest cover may also be affected by participation in water associations or PES schemes (e.g., Daniels et al., 2010; Kosoy et al., 2007), factors which were not studied here. We also anticipated that training would be an important determinant of EbA use, as some of the EbA practices (e.g., use of cover crops, use of shade in coffee) are known to be knowledge-intensive (Cerdán et al., 2012; Knowler and Bradshaw, 2007; Wall, 2007). However, we found no such relationship in the landscapes where we worked. The lack of relationships between EbA practices and training and technical support may simply reflect the fact that most farmers (76%) across our study sites have not received training in recent years and most lack access to technical extension, so there was little variation in these variables. In addition, in many cases the training or technical support received was focused on management practices that were not EbA. The gender of the household head also showed no relationship with EbA use or characteristics, in contrast to other studies that have clearly shown gender differences in the adoption of different farm management practices (e.g., Knowler and Bradshaw, 2007).

Finally, it is also important to note that certain specific EbA practices (the use of live fences, cover crops, fallows, forest patches and riparian forests) did not show any significant relationships with any of the biophysical or socioeconomic factors. For some practices, such as the use of cover crops and riparian forests, there were so few reported uses of these practices (3% and 9% of farmers, respectively), that our data set was likely too small to identify any factors affecting their use. In contrast, the use of live fences was common across all 6 landscapes (occurring on 68% of all farms surveyed), but was not associated with any of the factors studied. It is possible that other farmer-specific factors (not studied here) such as farmer income and availability of labor could influence their use (as these are commonly mentioned barriers to establishing live fences in new areas; Harvey et al., 2005), or alternatively that the use of this practice reflects other factors, such as availability of plant material for establishing new fences, which may not depend on individual farm or farmer characteristics. Additional studies are clearly needed to explore in more detail how farmers make decisions about the adoption and use of EbA practices, so that this information can be used to target interventions to those groups that are most likely to adopt and replicate the practices in the future.

4.3. Scaling up the use of EbA by smallholder farmers

Our study has several implications for the design and implementation of adaptation strategies for smallholder farmers across the region. First, it is important that governments, donors and practitioners recognize that many smallholder coffee and basic grain farmers are already actively using EbA practices and take advantage of this existing experience and local knowledge to promote and improve the use of EbA across smallholder farming communities. The fact that the abundance and characteristics of EbA practices vary across landscapes represents an important opportunity for cross-landscape learning and farmer-to-farmer exchanges. Organizing visits of farmers in regions where EbA practices are uncommon (but needed) to regions where these practices are widely used would allow farmers to directly share their knowledge of the benefits and drawbacks of EbA practices, and observe first-hand how the practices are implemented. Experiences elsewhere with farmer-to-farmer exchanges and field visits, combined with technical support, indicate this is a successful strategy for promoting the adoption of new farm management practices and may make farmers more inclined to adopt EbA practices on their farms (e.g., Braun et al., 2000; Holt-Giménez, 2002).

Second, there is a need to carefully assess the effectiveness of existing EbA practices and their contribution to farmer livelihoods, agricultural production and farm resiliency (Doswald et al., 2014), and effectively transfer this information to farmers and extension agents. More detailed analysis of the effectiveness of different EbA practices (and EbA practices with different characteristics) in different socio-economic and biophysical contexts would be helpful in identifying the most appropriate practices for a given location. For example, while there is some information on optimal shade levels for coffee plantations depending on climatic and altitudinal factors (e.g., Cerda et al., 2016; Jha et al., 2011; Staver et al., 2001), there is little information on what combination of tree species or what densities of trees are most likely to deliver specific adaptation benefits. For other EbA practices- such as dispersed trees in maize/bean fields or windbreaks- even less is known about the optimal configuration and design, and more rigorous scientific evidence of both the costs and benefits of these practices could help farmers to make more informed decisions about the use of these practices. Additional work is also warranted in identifying in which agroecological or socioeconomic contexts EbA practices are most effective at delivering adaptation benefits. More research is also needed on the combination of EbA practices with other adaptation strategies- such as the use of credit, the use of fertilizers, technology, climate information systems or insurance (Baca et al., 2014)- to better determine which combinations are most effective at enhancing farm and farmer resiliency. Actively engaging farmers in this assessment, evaluation and learning around EbA practices will be critical for both enhancing EbA adoption and developing practices that are tailored to the needs of smallholder farmers (Hellin and Ridaura-López,, 2016).

Finally, although certain EbA practices are common among smallholder, there is still significant scope to enhance the use of different EbA practices across farms and landscapes, increase the area under EbA on the farm and, in some cases, to diversify the species planted or maintained, or increase tree densities. For some EbA practices that were rarely used (such as the use of cover crops), there is a need to identify which factors currently constrain their use and develop strategies for overcoming these barriers. Studies in other regions have pointed to the importance of providing finance, research, training and extension to farmers to encourage adoption of new practices (e.g., Bryan et al., 2013; Deressa et al., 2011; Tucker et al., 2010) and it is likely that these same factors will be key for scaling up the use of EbA. Most smallholder farmers in our region have little, if any, access to credit or finance (Holland et al., 2017), which limits their ability to invest in adaptation measures. In addition, few have access to technical assistance or extension support (FAO, 2014; Holland et al., 2017), which could help them adapt EbA practices to their particular circumstances and needs. A final barrier which will need to be overcome (particularly in the Guatemalan and Honduran sites) is the lack of secure land tenure or cultivation rights, as the lack of tenure is known to be a major disincentive to farmers to plant or maintain tree cover on their farms or to make long-term investments in soil conservation and sustainable land management (e.g., Erenstein, 2003; Hellin and Ridaura-López, 2016).

5. Conclusions

To our knowledge, our study is the first to explicitly examine the use of EbA practices by smallholder farmers and to explore the factors associated with EbA use. Our study indicates that smallholder farmers in Central America are already using EbA practices (with a mean of 3.8 practices per farm), but that there is great variation in the prevalence of specific EbA practices. While some practices (such as live fences, home gardens, shade in coffee, dispersed trees in maize fields) are common on smallholder farms, other practices, such as the use of cover crops or windbreaks, are rarely used. Our study also indicates that a variety of biophysical and socioeconomic factors are associated with the use of EbA by smallholder farmers. The prevalence of EbA practices on the Central American smallholder farms studied suggests that many EbA practices are compatible with smallholder farming systems and that they merit greater attention in adaptation strategies, programs and policies aimed at enhancing the resiliency of smallholder farmer systems to climate change. Policy makers, donors and technicians can encourage the broader use of EbA by smallholder farmers by facilitating farmer-to-farmer exchanges to share knowledge on EbA implementation, assessing the effectiveness of EbA strategies in delivering adaptation benefits, and using this information to tailor EbA policies and programs for smallholder farmers in different socioeconomic and biophysical contexts.

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