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Research article

Influence of livelihood assets, experienced shocks and perceived risks on smallholder coffee farming practices in Peru

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ABSTRACT

Smallholder farmers might adopt different farming practices to cope with multiple stressors depending on their livelihood assets, and with varying environmental and economic outcomes. Ongoing global change is triggering stronger and different stressors that threaten conventional farming practices; however, this could be resolved if livelihood assets that drive decision making are actionable and thus can be modified. This study assessed the influence of farmers' livelihood assets, risk perception, and shocks on the choice of non-conventional farming practices for smallholder coffee farmers in San Martín, Peru. Using household survey data, we collected data on 162 coffee plantations along an elevation gradient. We operationalized the sustainable livelihoods framework for the adoption of shade and input coffee farming strategies and explored farmers' motives to change them. Despite associated high risks with pest and disease pressure, coffee price volatility and climate change, these risks did not explain the current shade and input farming strategies. While in the past five years, farmers adapted shade and input management in response to pest and disease and climate change pressures, these occurred in diverging directions: we found higher human and social assets associated with higher shade levels, and a trend for higher physical and financial assets associated with higher input use. These findings illustrate that two main factors affect decisions on farming practices related to shade and input management and they relate to different livelihood capitals. This suggests a potential for conflicting decision-making, push-and-pulling decisions in different directions. Further the disconnect between livelihood assets and perceptions suggests that perception of risk and shocks might not be sufficient to motivate decision making under changing conditions. Such insights in decision-making typologies and drivers can inform the development of farming practices that enhance resilience and sustainability of smallholder coffee production in Peru and elsewhere in the tropics.

1. Introduction

There is a global trend towards intensification of cultivation of tree crops such as oil palm, cocoa, rubber and coffee in the tropics, which is driven by the perceived higher economic performance of intensified systems that increases short-term income (Clough et al., 2011; Siebert, 2002). This intensification trend, however, occurs at the expense of the long-term maintenance of ecosystem services relevant for agricultural production (Foley et al., 2011). Millions of smallholders depend heavily on these tree crops for their livelihoods (Schroth and Ruf, 2014), making them vulnerable to volatile market prices and global environmental changes as soil degradation and climate change (Morton, 2007). Consequently, there is a need for management systems that are both productive and resilient, where alternative approaches align short-term gains with long-term benefits; for example, aligning enhanced crop yield and farmer income with maintenance of ecosystem services. Alternative approaches based on agro-ecological principles (Gliessman, 1992) seek to balance the maintenance of ecosystem services, and to reconcile economic and environmental goals (Altieri, 2002). Smallholder farmers adopt a wide range of tactics (short-term) and strategies

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(long-term; Rodriguez et al., 2014) with different environmental and economic outcomes, partially in response to stressors. Therefore, there is a need for a better understanding of the opportunities and constraints farmers experience while making decisions under uncertainty and in the context of global change. This understanding is relevant to recommend adoption of different strategies and develop farming practices.

Coffee is one of the tropical commodity crops for which the increasing worldwide demand is motivating coffee farmers to expand cultivated land (Defries et al., 2010; Laurance, 1999) and to intensify farming practices (Jha et al., 2014). An estimated 25 million farmers are growing coffee on over 11 million ha in more than 60 countries (Waller et al., 2007). These are predominantly smallholders (defined as farmers with less than 50 ha of land), and account for approximately 70% of global coffee production (Bacon, 2005). Market liberalization and integration have exposed farmers to volatile coffee prices (Eakin et al., 2014; Tucker et al., 2010), and a recent outbreak of coffee leaf rust (*Hemileia vastarix*) in Latin America reduced production by 10%–70% between 1983 and 2013 (Avelino et al., 2015; Jha et al., 2014). Predicted higher maximum temperatures and rainfall variability for coffee producing countries in Latin America (Imbach et al., 2017), might reduce coffee production and quality, increase susceptibility to pests, and change the most suitable locations for coffee plantations (Bunn et al., 2015). Typical intensification practices for coffee cultivation are the removal of shade trees (Aerts et al., 2011; Perfecto et al., 2015), increasing agro-chemical inputs, planting coffee shrubs in higher densities and planting new coffee varieties (Jha et al., 2014). Coffee smallholders are also applying agro-ecological or agroforestry practices, which are promoted by certification schemes, with lower dependence on agro-chemical inputs, higher shade levels and diversification of income (Perfecto et al., 2015; Ruf and Schroth, 2015).

Many criteria are involved in farmer decision making (Feola and Binder, 2010). Smallholder farmers can adopt strategies that either maximize economic performance and productivity (McGregor et al., 2001; Edwards-Jones, 2006), or minimise risks, stabilize income, and maintain food security (Schroth and Ruf, 2014). To employ such strategies, farmers make use of assets, for example, the use of natural and physical assets promotes the adoption of organic practices (Bravo-Monroy et al., 2016; Weber, 2011; Wollni and Brümmer, 2012), wealth and education of coffee farmers makes them adopt more environmentally-friendly farming practices (Chaves and Riley, 2001; Quiroga et al., 2015), and membership of farmers' cooperatives encourages the adoption of certification (Bravo-Monroy et al., 2016). Recently, a stronger emphasis has been on understanding the role of perception of risks, external pressures and shocks in farmer decision making (Feola et al., 2015; Levine, 2014). For example, Indonesian coffee farmers switched to cocoa in response to lower coffee prices (Paul et al., 2013), and Mexican farmers diversified their livelihoods when they perceived that coffee production collapsed (Padrón and Burger, 2015). Farmers may respond to a variety of shocks and stressors in different ways (Eakin et al., 2009), yet individuals must also have the motivation and ability to act.

The objective of this study is to understand what is driving smallholder decision making to adopt different shade and input farming practices for coffee systems. Based on previous research, it is clear that shade and input management are important variables that determine both socio-economic as well as environmental outcomes (e.g. Jezeer et al., 2018). We therefore postulate that different combinations of livelihoods assets, experienced shocks and perception of risks drive farmer decision making. Using the sustainable livelihoods framework (DFID, 1999; Scoones, 1998), we tested this hypothesis with a case study on the adoption of, and the motivations for farming practices varying in shade and input by smallholder coffee producers in San Martín, Peru. San Martín is one of the most important coffee producing regions of Peru (Vargas and Willems, 2017) and shade levels and input use in smallholder coffee farms range from plantations without shade trees to diversified shade, and from little or only organic input to use of chemical fertilizers, pesticides and herbicides (Jezeer et al., 2018). However, there is limited insight in motivations underlying the adoption of these different farming practices and how they might relate to the risks faced by farmers. Similar to coffee farmers worldwide, Peruvian coffee farmers are experiencing pressure due to volatile coffee prices (Larrea et al., 2014) and increased pest and disease incidence (Avelino et al., 2015), while climatic conditions in the country appear to be changing (Vargas, 2009). Therefore, we focus on these three pressures. Insights derived from this study are fundamental to support farmers in developing farming practices that enhance sustainability of smallholder coffee producers' livelihoods in Peru and elsewhere in light of ongoing global change. To our knowledge, this is the first of such a study for coffee systems in Peru, which not only evaluates shade and input separately but also explicitly includes perception of risks. In this study, we focus on a few aspects of farming systems (combination of management practices), in particular shade management and input management, which are discussed later on.

2. Methods

2.1. sustainable livelihoods approach

The sustainable livelihoods approach (SLA; DFID, 1999; Scoones, 1998) is widely recognised for offering an operational approach for understanding how farmer's livelihoods are shaped (e.g., Ellis, 2000). We use the definition for sustainable livelihood from Chambers and Conway (1991): *"a livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living"*. The SLA is an alternative to the single sector focus on production, employment and income as the sole concerns for livelihoods (Scoones, 2009). According to the SLA, livelihoods include both assets and strategies used by farmers or communities with the goal of improving their livelihoods. In our case, we modified the SLA to seek what livelihood assets of smallholder coffee farmers influence the adoption of shade and input strategies, and how these choices are affected by risks and shocks (Fig. 1). We chose to focus on practices strategies that define farming practices because these are more actionable for farmers, in contrast to livelihood outcomes and the institutional environment. To operationalize the SLA to our case study, we collected data on farmers livelihood assets, experienced shocks of coffee price volatility and pests and diseases, and perception of risks due to coffee price volatility, pests and diseases and climate change, as well as data on shade and input practices adopted by coffee farmers (Fig. 1). Due to a lack of location-specific meteorological data or high-resolution climate projections at the farm scale, it was not possible to include experienced shocks and pressures of climate change.

2.2. study region

The study was conducted in the department of San Martín, Peru, covering an area of approximately 2000 km^2. Only Arabica coffee (*Coffea arabica* L.), is grown in this region, of which Costa Rica 95 from the Catimor family and Iapar 59 are coffee rust-tolerant varieties, and Pache, Caturra, Típica, Borbón, Catuaí and Nacional are varieties more sensitive to coffee rust (Jezeer et al., 2018). Harvest occurs from February to June and peaks in April. Most Peruvian coffee farmers are not organised in farmer associations and the average farm size in the study region is 2.75 ha (CENAGRO, 2012). Common certification schemes are Organic, UTZ Fair Trade and Rain Forest Alliance. About 60% of Peruvian coffee plantations have multiple shade tree species, diversified shade, 23% have simplified shade, and 13% have no shade (Vargas and Willems, 2017). In general, shade seems to increase with elevation. Information on input management is limited, but input seems to decrease with elevation. Combinations of shade and input are possible as to have low input in both high shade and low shade systems, as well as

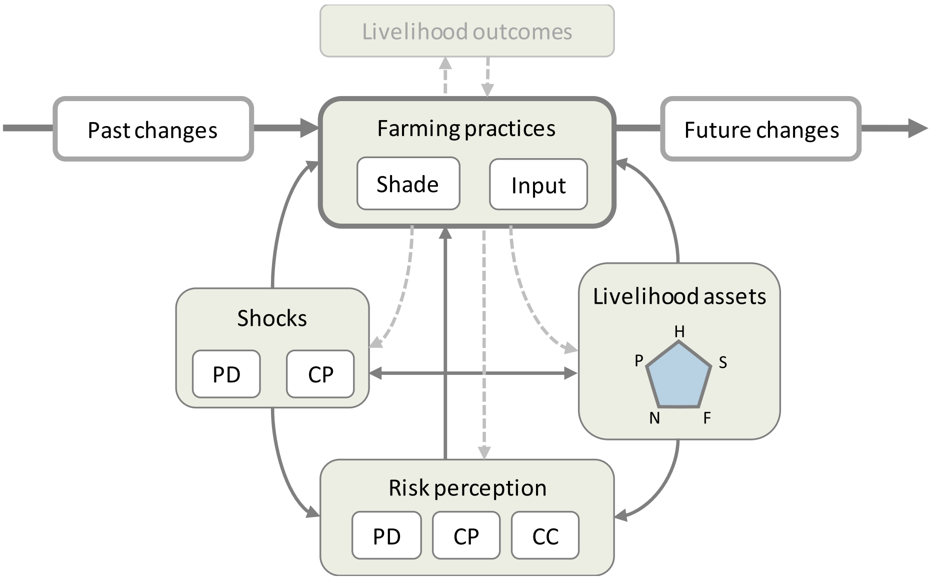

Fig. 1. Conceptual framework. PD = pests and diseases; CP = coffee price volatility; and CC = climate change. Livelihood capitals: H = Human, S = Social, N = Natural, P = Physical and F = Financial. Explored relations are depicted with solid arrows, while recognizing that there might be other feedback loops at play (dashed arrows).

have high input in low and high shade systems. Most plantations surveyed (n = 143) were situated in the provinces of Moyobamba and Rioja, which together form the ‘Alto Mayo’, a tropical highland with an average altitude of 1101 m (range 850–1497 m). The average rainfall is 1512 mm per year, the mean temperature 22.8 °C (Gobierno Regional de San Martín, 2008). The remaining 19 plantations were situated in the lowland province of Picota, with an average altitude of 861 m (range 673–1001 m). The nearest weather station (~ 20 km from these plantations at 218 m in elevation) reports a mean temperature of 26.5 °C and a mean annual rainfall of 937 mm (Gobierno Regional de San Martín, data collected between 1982 and 2012). The dry season occurs from May to September. Coffee price volatility is a major challenge for Peruvian coffee farmers as coffee prices more than tripled from 2004 to 2011, yet almost dropped again by half in 2013 (Larrea et al., 2014). Additionally, pests and diseases pose major risks as the recent coffee rust outbreak peaked in 2013 in Peru (Avelino et al., 2015) and caused a reduction of approximately 40% in national production.

2.3. survey and field sampling implementation

We performed household surveys to classify coffee systems in terms of shade and input (Jezeer et al., 2018) and to assess livelihoods assets, perception of risks and experienced shocks. These surveys were done twice; the first time in 2014 (n = 162) and the second time in 2016 (n = 77), both times using a semi-structured interview method and surveying the same farmers (see Fig. A1 for a diagram representing the structure of the collected data). The first sampling period was used to collect additional information on perception of risks and changes in farming practices, and to collect field data on shade tree density and species richness. Both sampling periods were from May to August. Plantation elevation was measured with a GPS (Garmin GPS 62s). Some farms had missing information for some variables, resulting in different number of observations (*n*) between variables.

Household surveys were conducted with 162 coffee farmers to characterise shade and input coffee farming practices, which in this study refer to a combination of shade management, input management, cultivated varieties, harvest timing and technique. Surveys were conducted in selected plantations that cover the full range of shade and input practices in the study area, either between full sun monoculture coffee to multi-layered shaded plantations, or from high agro-chemical input, to only organic inputs or without inputs. Farmers were recruited based on databases reporting certification and organizational levels (i.e., membership of farmers association) that also recorded some information on shade and input, and on local knowledge about their plantation characteristics. We only included coffee plantations owned by smallholder farmers that were older than three years and therefore were producing coffee berries with marketable beans (Perfecto et al., 1996). The interviewers were trained by the same person and surveys lasted between 45 and 60 min per farmer; most often plantation owners or tenants were interviewed. Surveyed farmers did not receive compensation for the survey. The interviewers assessed qualitatively if the farmers responded with confidence, and outliers were double checked. In 2016, data was collected and recorded in a smartphone/tablet app developed for this study, using ODK software (ODK Collect, version 1.4.10). The app included fields for each question, which provided guidance for the surveyors to minimise interview bias.

2.4. Data collection

2.4.1. Livelihood assets

Central to the SLA are capitals that describe the farmer's assets. The following five capitals are often considered: Human, Social, Natural, Physical and Financial (Ellis, 2000). To measure each of the five capitals we chose a set of indicators based on literature (Table 1; Baca et al., 2014; Chena et al., 2013; Fang et al., 2014; Garnett et al., 2007; Rahn et al., 2014; Table A1). To measure Human capital, we included a decision-making process indicator, that describes whether decisions are made by one or two household members (H1; Bravo-Monroy et al., 2016) and two indicators that describe ‘skills and knowledge’ (i.e., years of experience in coffee farming (H2) and level of education (H3)). Furthermore, Human capital was also measured by the availability of family labour as described by the number of household members who work on the coffee plantation (H4). For Social capital we used indicators that reflect the farmer's embeddedness in the community and membership of associations or cooperatives (S1 and S3), in addition to indicators reflecting support received from these networks (S2 and S4) and level of engagement in these networks (S5). Natural capital refers to the natural resource stocks and environmental services that people utilize (Scoones, 1998). We therefore selected indicators that reflected the vegetation complexity (shade tree density (N1) and shade tree species richness (N2)) on the coffee plantation as this is a proxy for biodiversity and provisioning of environmental services. Additionally, indicators coffee plantation size (N4) and perceived soil fertility (N3) were included in Natural capital as these also describe natural resources available to the farmers. Physical capital was described with indicators

Table 1
Description of variables and indices used for livelihood capitals, perception of risks and shocks. All continuous variables were standardized by: value/max, unless specified otherwise. For rationale behind chosen indicators and descriptive statistics, see Table A1.

		Abbr.	Description	Data description
Livelihood assets	Human	**H-index**	**Human index**	**ΣH1-4 (standardization = (value/max ΣH1-4)**
		H1	Family decisions made by multiple members of the family	0 = one person; 1 = > 1 person
		H2	Years of experience of coffee farming	Continuous, year
		H3	Level of education	0 = none; 0.33 = primary; 0.66 = secondary; 1 = tertiary
		H4	Farmers members working in the plantation	Continuous; number of persons
	Social	**S-index**	**Social index**	**ΣS1-5 (standardization = (value/maxΣS1-5))**
		S1	Family members and friends in the community	0 = no; 1 = yes
		S2	Support from family members and friends in community	0 = no; 1 = yes
		S3	Member of farmer association	0 = no; 1 = yes
		S4	Support from farmer association	0 = no; 1 = yes
		S5	Active participation in governance structure of farmer association	0 = no; 1 = yes
	Natural	**N-index**	**Natural index**	**ΣN1-4 (standardization = (value/maxΣN1-4)**
		N1	Shade tree density	Continuous, # trees per farm
		N2	Shade tree species richness	Continuous, # species per farm
		N3	Soil fertility	0 = not productive; 0.33 = somewhat productive; 0.66 = fertile; 1 = highly fertile
		N4	Coffee plantation size	Continuous, hectares
	Physical	**P-Index**	**Physical index**	**ΣP1-5 (standardization = (value/maxΣP1-5)**
		P1	Travel time to market for agricultural inputs and selling of beans	Continuous, minutes; (standardization = 1-(value/max))
		P2	Material of walls and floors	Material walls: 0 = non-cemented material or without corrugated tin; 0.25 = timber or corrugated tin; 0.5 = cement and brick casting/concrete. Material floor: 0 = dirt; 0.25 = brick or wood with non-cemented material; 0.5 = cement
		P3	Source of water	0 = well, stream or rain; 1 = tap
		P4	Source of light	0 = candle or kerosene; 1 = power network or solar
		P5	Food scarcity	continuous from 0 to 12 months (standardization = 1-(value/12))
	Financial	**F-index**	**Financial index**	**ΣF1-5 (standardization = (value/max ΣF1-5)**
		F1	Coffee farm income	Continuous, % of total farm income
		F2	Off-farm income	Continuous, % of total income
		F3	Share of hired labour	Continuous, %
		F4	Current open standing loans	0 = > S/.15.000; 0.25 = S/.10.000–15.000; 0.5 = S/.5.000–10.000; 0.75 = S/. 0–5000; 1 = S/. 0
		F5	Household savings	0 = S/. 0; 0.25 = S/. 0–5000; 0.5 = 5.000–10.000; 0.75 = S/. 10.000–15.000; 1 = S/.15.000
Risks	Climate change	**Perc**	**Climate change index**	**ΣPercCC1-7 (standardization = (value/maxΣPercCC1-7)**
		perCC1	Late rains	0 = absent; 0.25 = low; 0.5 = medium; 0.75 = high; 1 = very high
		perCC2	Increased intensity of rains	0 = absent; 0.25 = low; 0.5 = medium; 0.75 = high; 1 = very high
		perCC3	Early rains	0 = absent; 0.25 = low; 0.5 = medium; 0.75 = high; 1 = very high
		perCC4	More drought	0 = absent; 0.25 = low; 0.5 = medium; 0.75 = high; 1 = very high
		perCC5	More cold weather	0 = absent; 0.25 = low; 0.5 = medium; 0.75 = high; 1 = very high
		perCC6	Higher temperatures	0 = absent; 0.25 = low; 0.5 = medium; 0.75 = high; 1 = very high
		perCC7	Lower groundwater	0 = absent; 0.25 = low; 0.5 = medium; 0.75 = high; 1 = very high
	Pests and diseases	**perPD**	**Pests and diseases index**	**ΣPerPD1 + 2 (standardization = (value/maxΣPerPD1 + 2)**
		perPD1	Impact on coffee quality	0 = no/absent; 0.25 = low; 0.5 = medium; 0.75 = high; 1 = very high
		perPD2	Impact on coffee quantity	0 = no/absent; 0.25 = low; 0.5 = medium; 0.75 = high; 1 = very high
	Price fluctuations	**perCP**	**Coffee price fluctuation**	**0 = no/absent; 0.25 = low; 0.5 = medium; 0.75 = high; 1 = very high**
Shocks	Pests and diseases	**shockPD**	**Estimated loss due to coffee rust ('14)**	**Continuous, %**
	Coffee price variability	**shockCP**	**Variability in reported coffee price between '10 and '16**	**Continuous, € kg^{-1}**

of household's fixed assets (material of their houses, P2), access to energy (P4) and water (P3). Further, we selected indicators that described the distance to markets (P1) and the months per year that the household experiences food scarcity (P5). For Financial capital we used indicators depicting percentage of income derived from coffee (F1), portion of income derived from off-farm activities (F2), outstanding loans (F4) and current savings (F5) of the household. In addition, we included an indicator that described the portion of work that was conducted by family labour (F3), as an increased portion of hired labour may indicate a greater wealth. Data for F1, F2 and F3 was obtained from a previous study based on data collected on the same plantations (Jezeer et al., 2018), for which data on costs and benefits were collected (Table 1). For more detailed information on selection of indicators, see Table A1.

2.4.2. Experienced shocks

The SLA includes the impact of shocks, seasonality and trends on the farmers' livelihoods, which is referred to as the vulnerability context (DFID, 1999). Given the large impact of pests and diseases on coffee production in Peru over the last years, we used the average estimated coffee yield loss due to coffee rust (%) between ‘10 and ‘16 as indicator for experienced shocks of Pests and Diseases (shockPD). The variability in Coffee Price between ‘10 and ’16 (shockCP) was used as indicator for experienced shocks of coffee price volatility.

2.4.3. Risk perception

We also included farmers' perception of risks to assess if farmers perceive volatile coffee prices, pest and disease pressure and/or climate change events, and whether they consider these aspects to affect their livelihoods (Patt and Schroter, 2008). This was assessed for (i) Pests and Diseases (perPD) separately for coffee productivity and coffee bean quality, (ii) Coffee Price fluctuations (perCP), and (iii) seven Climate Change events (perCC) - the timing (early or late) and pattern of rainfall (increased intensity, more frequent periods of drought and lower groundwater level) and temperature (warmer or cooler periods; Table 1). For each of these possible risks, farmers were asked two questions (i) Did you experience any changes over the past five years?; (ii) If you experienced changes, what do you perceive the impact to be to your livelihood? In the analysis, the farmers who did not notice and the farmers who noticed changes but did not perceive impacts to their livelihood, were lumped together. Furthermore, farmers' greatest household concerns were also noted; farmers were asked to mark a maximum of three greatest concerns as an answer to “What worries you most when you think about possible effects on your household's well-being in the coming year?” (adapted from Frank et al., 2011; Tucker et al., 2010). These concerns were categorized as directly or indirectly associated with the farm and coffee plantation. To gain insight in the motivations for changes in strategies over time, farmers were asked to report the changes instrategies over the past 5 years and the motivation for these changes, in particular level of shade (lower (↓), unchanged (∼) or higher (↑)), and level of input (↓, ∼ or ↑). Farmers were also asked if they were planning to change shade levels (↓, ∼ or ↑) in the coming five years, along with their main motivation to do so.

2.4.4. Input management

Data on input management was collected by asking farmers about fertilizing, weeding and pest and disease control activities. As fertilizer or pesticide inputs are partly used as concentrates, the total value of applied inputs was considered (€ ha^{-1} y^{-1}, excluding labour), assuming a positive correlation between the concentration of active substances and price (Table A2). Additionally, the type of fertilizer (organic or chemical) and weeding method applied (by hand using a machete, mechanically by using a brush-cutter, or by applying herbicides) were considered as indicators of intensity of input management.

2.4.5. Shade management

Tree species richness was assessed with the data collected in 2016 by asking farmers about the species and numbers of trees present at their coffee plantations. To assess survey data reliability, farmers were asked to rank the difficulty in estimating the number and species of trees present at their coffee farm (easy, medium or difficult). If they found this ‘difficult’ the answer was not included in the database. Additionally, we checked for interviewer and farmer bias by comparing survey data to plot data (See Supplementary materials, Fig. A2).

We used the input and a shade index for each coffee plantation that we calculated in a previous study (Jezeer et al., 2018); these indices are similar to those used in other coffee studies (Bisseleua Daghela et al., 2013; Hernández-Martínez et al., 2009; Mas and Dietsch, 2003). The input index is an aggregate of five management variables that describe fertilizing, weeding and pest and disease control activities, while the shade index is based on shade tree density and shade tree species richness. For both input and shade indices, Low, Medium and High classes were established using a K-mean cluster analysis (see Table A3 and Jezeer et al. (2018) for more information on index development).

2.5. Data analyses

All indicator values were standardized to range between 0 and 1 (Table 1). For continuous variables, this was done by dividing the observed farm value by the maximum observed value across the sample. Categorical variables were assigned values between 0 and 1 (Table 1). Indices for each livelihood capital and perceived risks were computed by rescaling the sum of the ranks for the associated variables to values between 0 and 1. Equal weights were used in the final aggregated indicator per capital.

To assess whether farmers' perceptions, experienced shocks or livelihood capitals differed between input and shade levels, we used an ANOVA followed by a Tukey HSD post-hoc test when data had a normal distribution, or a non-parametric Kruskal–Wallis test followed by a Dunn's post-hoc test when data failed to meet the normality assumption. Normality of data was assessed using Shapiro-Wilk test and heteroscedasticity was tested using Levene's test. We used a Bonferroni correction to correct for multiple comparisons and adjusted P-values are presented.

Finally, to identify farmer decision making profiles, we used a principal component analysis (PCA) in two steps. First, we ran a PCA with all variables for livelihood assets, experienced shocks and risk perception so see whether farmer decision making profiles emerged. Secondly, shade and input management indices and elevation, were included as vectors in the PCA to assess whether they aligned with farmer decision making profiles. Significance level was set at $\alpha = 0.05$. Statistical analyses were performed with R (version 3.0.2, R Core Team, 2014), using the ‘mclust’ (Fraley et al., 2017), ‘factoextra’ (Kassambara and Mundt, 2017) and ‘car’ (Fox et al., 2016) packages.

3. Results

3.1. Current input and shade management

Farm average size was 6.4 ± 8.4 ha, with an average coffee cultivation area of 2.7 ± 2.0 ha, and farmers spent on average 149.7 ± 196.9 € ha^{-1} y^{-1} on inputs (Table A2). Low-Input plantations (n = 23) did not have pest and disease control activities, and fertilizer application and weeding was done manually (Table A3). Medium-Input plantations were the largest group (n = 50), and farmers spent on average 124 € ha^{-1} y^{-1} on predominantly organic fertilizers. Also, 40% of these farmers applied pest and disease control, largely organic. The majority of Medium-Level input farmers weeded manually, while a small fraction weeded mechanically. High-Input plantations (n = 37) often recurred to mechanical weeding and applied non-organic herbicides. All High-Input farmers applied fertilizers with an average expenditure of 220 € ha^{-1} y^{-1}, and spent on average 80 € ha^{-1} y^{-1} on pesticides and/or fungicides (Table A3).

The studied farms had a high variability of tree densities, with 71 ± 105 trees ha^{-1} (Table A2). The Low-Shade class (n = 45) had a mean density of 19 ± 20 trees ha^{-1}, often with a single tree species. The Medium-Shade plantations (n = 27) had an average density of 52 ± 35 trees ha^{-1}, with four species on average. High-Shade plantations (n = 19) had an average of 153 ± 149 trees ha^{-1}, with seven species on average.

Table 2
Statistics (mean ± SD) of livelihood capitals, perception of risks and pressures for the Input and Shade classes. Significant differences between groups were evaluated using an ANOVA followed by a Tukey HSD post-hoc test with a Bonferroni correction when data conformed with normality requirements (indicated with (i)) or with a Kruskal–Wallis non-parametric test followed by a Dunn's post-hoc test with a Bonferroni correction (not indicated) when data was non-normal. The level of significance (adjusted): ns at $P > 0.10$;. $P < 0.10$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$. Different letters indicate significant differences among shade and input classes. Standardized values are reported; see Table A2 for description of variables and formula for standardizing value.

			Shade					Input				
			Low	Medium	High	*sig*	*Post-hoc test*	Low	Medium	High	*sig*	*Post-hoc*
			mean ± sd	mean ± sd	mean ± sd			mean ± sd	mean ± sd	mean ± sd		
Livelihood assets	Human	**H-index**	**0.47 ± 0.15(a)**	**0.61 ± 0.19**	**0.67 ± 0.22(b)**	**	**High > Low**	**0.54 ± 0.25**	**0.62 ± 0.19**	**0.57 ± 0.21**		
		H1	0.33 ± 0.49	0.67 ± 0.48	0.69 ± 0.47	.	High > Low	0.50 ± 0.53	0.71 ± 0.46	0.48 ± 0.51		
		H2	0.28 ± 0.21(a)	0.36 ± 0.20(b)	0.40 ± 0.19(b)	**	High&Medium > Low	0.32 ± 0.19	0.34 ± 0.21	0.39 ± 0.21		
		H3	0.40 ± 0.16	0.4 ± 0.18	0.40 ± 0.18			0.41 ± 0.20	0.39 ± 0.18	0.38 ± 0.14		
		H4	0.34 ± 0.11	0.39 ± 0.14	0.42 ± 0.21			0.30 ± 0.05	0.39 ± 0.17	0.37 ± 0.16		
	Social	**S-index**	**0.56 ± 0.31**	**0.54 ± 0.28**	**0.69 ± 0.26**			**0.68 ± 0.34**	**0.66 ± 0.30**	**0.49 ± 0.27**		
		S1	0.87 ± 0.35	0.88 ± 0.34	0.86 ± 0.36			1.00 ± 0.00	0.88 ± 0.34	0.76 ± 0.44		
		S2	0.60 ± 0.51	0.50 ± 0.51	0.46 ± 0.51			0.62 ± 0.52	0.54 ± 0.51	0.38 ± 0.50		
		S3	0.31 ± 0.47(a)	0.61 ± 0.49(b)	0.77 ± 0.42(b)	***	High&Medium > Low	0.48 ± 0.51	0.60 ± 0.49	0.49 ± 0.51		
		S4	0.47 ± 0.52	0.46 ± 0.51	0.74 ± 0.44	.	High > Medium	0.50 ± 0.53	0.67 ± 0.48	0.52 ± 0.51		
		S5	0.43 ± 0.51	0.26 ± 0.45	0.53 ± 0.51			0.50 ± 0.53	0.48 ± 0.51	0.25 ± 0.44		
	Natural	**N-index**	**0.28 ± 0.11(a)**	**0.36 ± 0.08(a)**	**0.56 ± 0.18(b)**	***	**High > Medium&Low** (i)	**0.50 ± 0.22**	**0.42 ± 0.16**	**0.41 ± 0.16**		
		N1	0.03 ± 0.03(a)	0.07 ± 0.05(b)	0.22 ± 0.21(c)	***	High > Medium > Low	0.10 ± 0.15	0.10 ± 0.14	0.10 ± 0.11		
		N2	0.05 ± 0.05(a)	0.18 ± 0.06(b)	0.34 ± 0.18(c)	***	High > Medium > Low	0.20 ± 0.19	0.19 ± 0.14	0.18 ± 0.13		
		N3	0.38 ± 0.17	0.42 ± 0.15	0.49 ± 0.20			0.50 ± 0.25	0.42 ± 0.15	0.44 ± 0.19		
		N4	0.58 ± 0.21	0.63 ± 0.19	0.65 ± 0.23			0.48 ± 0.36	0.62 ± 0.18	0.58 ± 0.22		
		N5	0.18 ± 0.12	0.19 ± 0.10	0.25 ± 0.18	.	High > Low	0.18 ± 0.10	0.21 ± 0.14	0.20 ± 0.11		
	Physical	**P-Index**	**0.74 ± 0.16**	**0.66 ± 0.19**	**0.66 ± 0.20**	.	**ns**	**0.63 ± 0.28**	**0.70 ± 0.17**	**0.72 ± 0.14**		
		P1	0.24 ± 0.18	0.21 ± 0.20	0.19 ± 0.19			0.20 ± 0.15	0.21 ± 0.21	0.21 ± 0.16		
		P2	0.38 ± 0.33	0.30 ± 0.30	0.36 ± 0.33			0.40 ± 0.32	0.32 ± 0.33	0.32 ± 0.31		
		P3	0.77 ± 0.36	0.68 ± 0.40	0.62 ± 0.41			0.61 ± 0.45	0.69 ± 0.41	0.78 ± 0.34		
		P4	0.78 ± 0.41	0.79 ± 0.41	0.75 ± 0.43			0.61 ± 0.49(a)	0.80 ± 0.39	0.88 ± 0.32(b)	*	High > Low (p = 0.043)
		P5	0.65 ± 0.16	0.68 ± 0.15	0.71 ± 0.17			0.66 ± 0.19	0.71 ± 0.16	0.68 ± 0.14		
	Financial	**F-index**	**0.64 ± 0.19**	**0.57 ± 0.18**	**0.55 ± 0.15**			**0.55 ± 0.12**	**0.58 ± 0.19**	**0.63 ± 0.17**		
		F1	0.36 ± 0.35	0.32 ± 0.27	0.33 ± 0.29			0.26 ± 0.24	0.41 ± 0.33	0.34 ± 0.34		
		F2	0.18 ± 0.30	0.12 ± 0.20	0.08 ± 0.19			0.15 ± 0.20	0.09 ± 0.17	0.14 ± 0.31		
		F3	0.61 ± 0.38	0.68 ± 0.33	0.61 ± 0.33			0.62 ± 0.30	0.63 ± 0.34	0.78 ± 0.30	.	High > Low (p = 0.078)
		F4	0.90 ± 0.13	0.84 ± 0.22	0.81 ± 0.27			0.81 ± 0.22	0.85 ± 0.21	0.82 ± 0.28		
		F5	0.08 ± 0.22	0.13 ± 0.27	0.08 ± 0.18			0.00 ± 0.00	0.10 ± 0.21	0.10 ± 0.26		

(*continued on next page*)

Table 2 (*continued*)

			Shade					Input				
			Low	Medium	High	*sig*	*Post-hoc test*	Low	Medium	High	*sig*	*Post-hoc*
			mean ± sd	mean ± sd	mean ± sd			mean ± sd	mean ± sd	mean ± sd		
Perception of risks on livelihoods	Climate change	**perCC**	**0.43 ± 0.23**	**0.52 ± 0.24**	**0.50 ± 0.21**			**0.59 ± 0.07**	**0.46 ± 0.23**	**0.40 ± 0.21**	.	**Low > High (p = 0.08)** [(i)]
		perCC1	0.17 ± 0.20	0.25 ± 0.22	0.26 ± 0.30			0.31 ± 0.26	0.24 ± 0.29	0.19 ± 0.22		
		perCC2	0.02 ± 0.07	0.04 ± 0.12	0.14 ± 0.23	.	ns	0.16 ± 0.23	0.07 ± 0.17	0.02 ± 0.08		
		perCC3	0.00 ± 0.00	0.02 ± 0.10	0.04 ± 0.15			0.06 ± 0.18	0.01 ± 0.05	0.00 ± 0.00		
		perCC4	0.32 ± 0.26	0.35 ± 0.22	0.28 ± 0.28			0.25 ± 0.23	0.31 ± 0.29	0.37 ± 0.23		
		perCC5	0.23 ± 0.24	0.29 ± 0.25	0.31 ± 0.28			0.47 ± 0.25	0.27 ± 0.26	0.20 ± 0.23	.	ns
		perCC6	0.57 ± 0.24	0.56 ± 0.30	0.54 ± 0.23			0.59 ± 0.13	0.53 ± 0.26	0.51 ± 0.28		
		perCC7	0.10 ± 0.23	0.16 ± 0.28	0.04 ± 0.11			0.06 ± 0.18	0.06 ± 0.15	0.04 ± 0.10		
	Pests and diseases	**perPD**	**0.62 ± 0.14**	**0.59 ± 0.31**	**0.69 ± 0.23**			**0.69 ± 0.21**	**0.67 ± 0.24**	**0.65 ± 0.54**		
		PerPD1	0.60 ± 0.21	0.57 ± 0.33	0.66 ± 0.27			0.69 ± 0.29	0.66 ± 0.27	0.65 ± 0.26		
		perPD2	0.63 ± 0.23	0.60 ± 0.33	0.71 ± 0.24			0.69 ± 0.29	0.68 ± 0.27	0.65 ± 0.30		
	Price fluctuations	**perM**	**0.63 ± 0.23**	**0.66 ± 0.28**	**0.46 ± 0.29**	*	**Medium > High (p = 0.055)**	**0.56 ± 0.40**	**0.57 ± 0.31**	**0.54 ± 0.25**		
Experienced shocks	Pests and diseases	**shockPD**	**0.38 ± 0.28**	**0.46 ± 0.21**	**0.48 ± 0.23**			**0.56 ± 0.19(a)**	**0.48 ± 0.21**	**0.35 ± 0.26(b)**	**	**Low > High**
	Coffee price variability	**shockCP**	**0.40 ± 0.16**	**0.44 ± 0.19**	**0.38 ± 0.18**			**0.38 ± 0.21**	**0.40 ± 0.18**	**0.43 ± 0.16**		

3.2. Farmers' livelihoods capitals

Human capital was significantly higher for High-Shade plantations compared to Low-Shade ($z = 3.2$; $p_{adj} = 0.004$; Table 2). This was predominantly due to the years of experience of farming coffee, as farmers applying Low-Shade had significantly less coffee-farming experience than those applying High-Shade ($z = 3.4$; $p_{adj} = 0.002$) or Medium-Shade ($z = 2.4$; $_{padj} = 0.043$). Although no difference was observed for Social capital, significantly more High-Shade and Medium-Shade than Low-Shade farmers were members of a farmers' organisation (High-Low: $z = 4.2$; $p_{adj} = 0.000$; Medium-Low: $z = 2.8$; $p_{adj} = 0.02$). There was also a trend for High-Shade plantations to be larger in area than Low-Shade ($z = 2.4$; $p_{adj} = 0.056$). No differences in Financial assets were found for plantations with different shade levels (Table 2).

Livelihood capitals associated with input levels were different from those associated with shade levels. We observed that High-Input plantations had significantly higher use of electricity as source of light than Low-Input plantations ($z = 2.45$; $p_{adj} = 0.043$). Physical assets did not differ between Input groups. We found a trend for percentage of hired labour being lower for Low-Input plantations compared to High-Input plantations ($z = 2.23$; $p_{adj=}0.078$; Table 2).

3.3. Farmer decision making profile

We identified two farmer decision-making profiles in the PCA space (Fig. 2), based on the first two PCA axes. The first decision-making profile were clustered on the positive values of PCA axis 1 and on the negative values of PCA axis 2 and includes Human, Natural and Social capitals which overlap with shade index, suggesting a shade-based decision profile. Human, Natural and Social capitals all have positive loadings for PCA axis 2. This shade-based decision profile was opposite (i.e. negatively correlated) to perception of coffee price volatility, climate change and shocks of coffee price volatility. The second decision-making profile located on the negative side of PCA axis 1 and negative side of PCA axis 2 (input-based decision) links Financial and Physical capitals (all with negative loadings for PCA axis 1) and overlapped with input index. This decision profile was opposite to elevation, and perception and shocks from pests and diseases (located on the positive side of PCA axis 1 and positive side of PCA axis 2). The first two axes of the PCA explained 32.9% of variability in perception of risks, livelihood capitals and experienced shocks. Loadings for the PCA are presented in Table A4.

3.4. Risk perception and experienced shocks

Farmers perceived pests and diseases, coffee price volatility, and increased temperatures as major risks for their livelihoods (Table 2, Fig. A3a). There was a significant difference between farmers with different levels of shade ($P = 0.04$, Table A2) in perceived risk of coffee price fluctuations. A more robust Dunn's post-hoc test with Bonferroni correction showed that there was a trend that farmers with High-Shade levels perceived lower risks due to coffee price variability than farmers with Medium-Shade ($z = 2.36$; $p_{adj} = 0.055$). No further significant differences in perceived risks were observed between plantations with different shade levels or input levels. Shocks due to pests and diseases were significantly higher for farmers with Low-Input than farmers with High-Input levels ($z = 3.2$; $p_{adj} = 0.005$). The majority of the farmers indicated that their greatest concern was coffee price fluctuations, followed by pest and disease impact (Fig. A3b).

3.5. Changes in farming practices

A third of the farmers reported to have increased shade levels, and 60% ($n = 14$) of those mentioned climate change as main driver, while 74% of the farmers that decreased shade were motivated to reduce shade levels due to pests and disease (*n = 17;* Fig. 2c). Approximately 65% (*n = 49*) of the farmers reported to have increased inputs, while the others farmers reported no changes in input level. Pest and disease pressure was the main driver to increase input levels (n = 41), both for organic and chemical inputs.

4. Discussion

In this study we assessed the influence of farmers' livelihoods assets, experienced shocks, and risk perception on the adoption of shade and input strategies to better understand their decision-making process. Higher levels of human and social capitals were associated with higher shade; while, livelihood capitals were negatively related to experienced shocks and perception of risks. Currently, farmers showed a high perception of risks from pest and diseases, followed by coffee price volatility and increased temperatures.

4.1. Livelihood capitals

Human and social capitals were associated with higher shade levels, along with natural capital. In our study, farmers with more years of experience in coffee cultivation had higher shade levels in their plantations, and this finding is in line with other studies that have shown that adoption of environmentally friendly farming practices are positively influenced by farmers' skills, knowledge and experience (Chaves and Riley, 2001; Quiroga et al., 2015). A large share of these Peruvian coffee farmers with high shade was member of a farmers' organisation often providing coffee certification. This is similar to coffee farmers from Costa Rica (Wollni and Brümmer, 2012) and Colombia (Bravo-Monroy et al., 2016). This could be because farmers who are member of an organisation might gain access to more information, updated practices and knowledge (Frank et al., 2011), and specialty markets (Wollni and Brümmer, 2012), and might receive higher coffee prices with certification premiums (Muschler, 2001). As natural capital included shade tree species richness and density, logically, it was linked to high shade

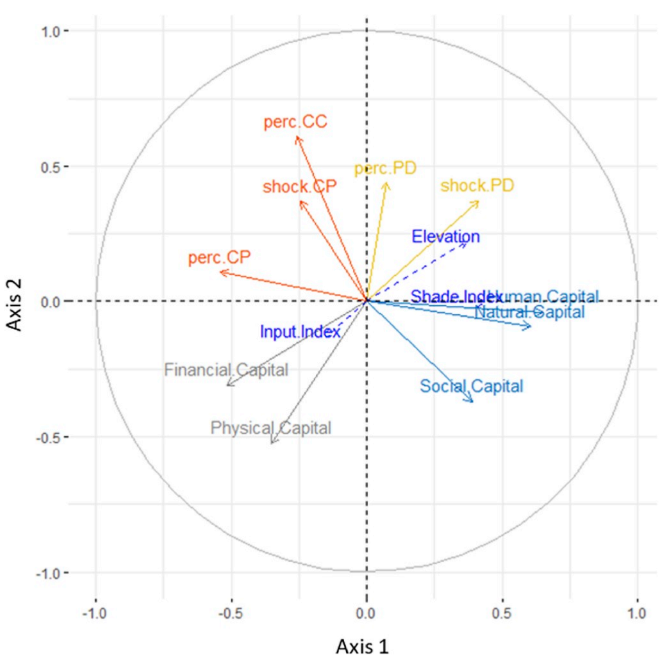

Fig. 2. PCA of livelihood capitals (H, S, N, P and F), perception of risks of price variability (perc.CP), pests and diseases (perc.PD) and climate change (perc.CC); and experienced pests and diseases (shock.PD) and price volatility (shock.CP). Elevation, Shade Index and Input Index are supplementary variables (dotted arrows). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

levels. Similar to other studies (Bravo-Monroy et al., 2016; Weber, 2011; Wollni and Brümmer, 2012), there was a trend that plantations with higher levels of shade were larger, which might provide an added benefit by their potential to conserve biodiversity, carbon storage and other ecosystem services (Bhagwat et al., 2008; De Beenhouwer et al., 2013).

On the other hand, decision-making over input strategies was influenced by financial and physical capitals. We found that financial capital was associated with input use, which is in line with other studies that found that wealthier farmers could invest more in inputs to enhance farm output (Bullock et al., 2014; Rahman, 2003). Other studies have shown that the lack of financial assets limits access to inputs (Chaves and Riley, 2001). This is also the case in our study, where a few farmers who decreased or did not change their input levels mentioned that this was due to lack of financial means. Bean and Nolte (2017) reported that a significant portion of Peruvian coffee exports are organic, and explained this high proportion of organic coffee producers by the smallholder's inability to pay for chemical fertilizers and pesticide. Financial and physical capitals are possibly negatively related with elevation because farmers who live at higher elevations have lower access to markets to sell their coffee and have to travel longer distances to purchase fertilizer and pesticide.

4.2. Experienced shocks and perceived risks

Perceived risks of pest and disease pressure, coffee price volatility and increased temperatures were high, but did not explain farmers' current shade and input strategies. This could be because farmers might not always have the capacity or means to respond to their perceptions. For example, Tucker et al. (2010) found that farmers who perceived high risk were not more likely to engage in specific adaptations, and adopted strategies more clearly associated with livelihood assets such as access to land and membership of farmer organisation. Perceived risks showed strong coherence with experienced shocks in the past and this might be explained by farmers having learned from previous experiences. These findings highlight the importance of farmer's experience rather than knowledge of projected risks into the future. Overall, these results suggest that adoption of farming practices was more strongly influenced by livelihood assets than perception of risks.

4.3. Farmers strategies for enhanced resilience

The greatest concern of farmers was related to the fluctuating coffee prices rather than extreme climate or pest and disease events. This finding is consistent with evidence from other studies of farm communities and climate risk (Eakin, 2005; Tucker et al., 2010). This seems to underline the role of economic factors in decision making. However, there appears to be a disconnect between the perceived risks and the changes made; rather than fluctuating coffee prices, pest and disease impact and climate change events were driving changes in shade and input management over the past five years. These pressures lead to opposing strategies: climate change perception motivated farmers to increase shade levels, while pressure from pests and diseases led to a reduction in shade. Reconciling these opposing strategies is fundamental as shade trees are expected to improve farmer's resilience to climate change, amongst other by buffering micro-climate (Lin, 2007). Farmers thus seem to be aware of the long-term risks of climate change, and appear willing to adapt their management accordingly. This is not surprising, as coffee is very sensitive to changes in climate (Bunn et al., 2015; DaMatta, 2004) and consequently farmers livelihoods. In contrast to climate change, pest and disease shocks require a more immediate response; in this study, farmers reported that the latter motivated them to reduce shade levels and increase inputs. Further, there is a potential interaction effect between shade and input management, as studies reported that shade can have either negative or beneficial effects on pests and diseases, including coffee leaf rust (Jackson et al., 2012;

Jonsson et al., 2015). There appears to be an interest to move towards more shaded systems as about 60% of the farmers considered increasing shade levels in the future (Fig. A3a). This seems predominantly motivated by future timber revenues, but also by indirect benefits of shade trees such as buffering climate change effects, soil erosion control, enhanced soil fertility and improved bean quality (Fig. A3a). However, concerns like lack of land ownership (Mercer, 2004), lack of knowledge and limited access to seedlings and timber market (Cerda et al., 2014; Schroth and Ruf, 2014; Fig. A3b) may be barriers to increase in shade levels. Generally, shade and input management decisions aim at reducing pest and disease and climate pressures, as to maintain coffee productivity or increase overall income, rather than maintaining a broad range of ecosystem services.

4.4. Recommendations for practitioners and policy-makers to support smallholder resilience

To support adoption of farming practices, we recommend considering variation in livelihood assets to enable tailored support to farmer or farmer groups. When the aim is to move towards more environmentally-friendly farming practices, it is of particular importance to assess farmers' embeddedness in the community, membership of a farmers organisation and experience with cultivating coffee, as these have been identified as important assets. Since these farmer groups and knowledge assets are actionable, i.e. can be changed, they provide a promising avenue for the adoption of more-environmentally friendly farming practices. We believe these assets are more easily changeable because some farmers are already participating in cooperatives, exchanging information on certification, and several NGOs are already on the ground providing knowledge and information. Further development of farmers organisations will likely improve access to information and provide technical assistance to coffee farmers, provide information on the advantages and disadvantages of diversification, and improve market access to both coffee and shade tree products. These actions are starting to occur on the ground, especially as Peru is growing in importance in the global coffee market. Nonetheless, while actionable and promising, further research is needed to assess the outcomes of such associative activities. Also, it is important to understand the opportunities and barriers faced by farmers for the use of shade trees on their coffee plantations, in particular when promoting the adoption of agroforestry systems as part of some certification schemes. Lastly, we recommend that farmer's financial and physical assets are assessed, as we found some support that these pose important constraints to the adoption of the use of inputs use. Credit facilities for smallholder farmers could help overcome such financial constraints.

4.5. Data limitations and future research

Though we included multiple factors in this analysis using SLA, this study has some caveats that need to be taken into consideration. First, we chose not to include the institutional environment, although this links livelihood assets and farming strategies in SLA (Scoones, 1998) as other institutions may promote or impose decisions beyond farmer decision power and association norms and rules. It would be important to study to which extent our results hold when other institutions are considered, or if indirectly their effect is already embedded. Secondly, while joining an organisation or certification scheme can be an important way for farmers to reduce their vulnerability to pressures, changes in membership of farmers organisations and/or certification were not considered. Third, we were unable to include experienced changes in climate over the past years, though farmers reported to perceive high risks related to climate change suggesting that actual experienced climate change might also play a role in decision making. From a methodological point of view we chose to give equal weight to all the indicators as we had no prior knowledge to inform other types of weighting schemes and this way we would not bias our results due to misinformed weights. Future work should expand on this and explore how the results might be influenced by simulated weights or investigate the strength of the relations to derive empirical weights. Fourth, changes in farming practices were recorded by farmer surveys rather than observations over time. We trust that the answers are given to the best of their knowledge, but this means that the data reflect what the respondents reported. Lastly, we chose to use only one indicator for pests and diseases; while this becomes uneven with other indicators, there was no other option to integrate more indicators for this aspect. We believe however that this is a good depiction of the pressure over coffee at the time of the study as the coffee rust had a very strong effect on coffee productivity.

5. Conclusions

The sustainable livelihoods approach allowed for more comprehensive insight into decision making of smallholders on the adoption of farming practices, moving beyond a focus on merely economic factors as productivity and income. To our knowledge, this is the first study of such studies in coffee systems in Peru, explicitly including shade and input management separately. Generally, this study contributes to the body of literature that suggests that livelihood factors such as embeddedness in the community, membership of a farmers organisation and experience with coffee cultivation are important for the adoption of strategies for smallholder coffee farmers. Our results also show that risk perception and experience with disturbances alone remain insufficient to motivate adoption of farming practices. We found a set of actionable assets that differ for shade and input management; whilst human, social and natural assets may limit or enhance adoption of environmentally-friendly management systems, financial and physical assets may affect adoption of input strategies. The different timescales at which pest and climate pressures may interfere with farmers' livelihoods are important to take into account. Extending the livelihood framework can help identify farming practices that are able to reconcile livelihood assets, so that economic and environmental performance can coincide.

Declaration of interest statement

The contents of this manuscript have not been published elsewhere and are not being considered at another journal. All authors have approved the manuscript contents, declare having no competing interests, and agree with its submission to Journal of Environmental Management.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2019.04.101.

References

Aerts, R., Hundera, K., Berecha, G., Gijbels, P., Baeten, M., Van Mechelen, M., Hermy, M., Muys, B., Honnay, O., 2011. Semi-forest coffee cultivation and the conservation of Ethiopian Afromontane rainforest fragments. For. Ecol. Manage. 261, 1034–1041.

https://doi.org/10.1016/j.foreco.2010.12.025.
Altieri, M.A., 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. Agric. Ecosyst. Environ. 93, 1–24. https://doi.org/10.1016/S0167-8809(02)00085-3.
Avelino, J., Cristancho, M., Georgiou, S., Imbach, P., Aguilar, L., Bornemann, G., Läderach, P., Anzueto, F., Hruska, A.J., Morales, C., 2015. The coffee rust crises in Colombia and Central America (2008–2013): impacts, plausible causes and proposed solutions. Food Secur 7, 303–321. https://doi.org/10.1007/s12571-015-0446-9.
Baca, M., Laderach, P., Haggar, J., Schroth, G., Ovalle, O., 2014. An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in mesoamerica. PLoS One 9. https://doi.org/10.1371/journal.pone.0088463.
Bacon, C., 2005. Confronting the coffee crisis: can fair trade, organic, and specialty coffees reduce small-scale farmer vulnerability in northern Nicaragua? World Dev. 33, 497–511. https://doi.org/10.1016/j.worlddev.2004.10.002.
Bean, C., Nolte, G.E., 2017. Peru- Coffee Annual- Peruvian Coffee Production Bouncing Back. USDA Foreign Agricultural Services; Global Agricultural Information Network.
Bhagwat, S.A., Willis, K.J., Birks, H.J.B., Whittaker, R.J., 2008. Agroforestry: a refuge for tropical biodiversity? Trends Ecol. Evol. 23, 261–267. https://doi.org/10.1016/j.tree.2008.01.005.
Bisseleua Daghela, H.B., Fotio, D., Yede Missoup, A.D., Vidal, S., 2013. Shade tree diversity, cocoa pest damage, yield compensating inputs and farmers' net returns in West Africa. PLoS One 8, e56115. https://doi.org/10.1371/journal.pone.0056115.
Bravo-Monroy, L., Potts, S.G., Tzanopoulos, J., 2016. Drivers influencing farmer decisions for adopting organic or conventional coffee management practices. Food Policy 58, 49–61. https://doi.org/10.1016/j.foodpol.2015.11.003.
Bullock, R., Mithöfer, D., Vihemäki, H., 2014. Sustainable agricultural intensification: the role of cardamom agroforestry in the East Usambaras, Tanzania. Int. J. Agric. Sustain. 12, 109–129. https://doi.org/10.1080/14735903.2013.840436.
Bunn, C., Laderach, P., Ovalle Rivera, O., Kirschke, D., 2015. A bitter cup: climate change profile of global production of Arabica and Robusta coffee. Clim. Change 129, 89–101. https://doi.org/10.1007/s10584-014-1306-x.
CENAGRO, 2012. Censo Nacional Agropecuario 2012. (Lima).
Cerda, R., Deheuvels, O., Calvache, D., Niehaus, L., Saenz, Y., Kent, J., Vilchez, S., Villota, A., Martinez, C., Somarriba, E., 2014. Contribution of cocoa agroforestry systems to family income and domestic consumption: looking toward intensification. Agrofor. Syst. 88, 957–981. https://doi.org/10.1007/s10457-014-9691-8.
Chambers, R., Conway, G.R., 1991. Sustainable Rural Livelihoods: Practical Concepts for the 21st Century. 0903715589.
Chaves, B., Riley, J., 2001. Determination of factors influencing integrated pest management adoption in coffee berry borer in Colombian farms. Agric. Ecosyst. Environ. 87, 159–177. https://doi.org/10.1016/S0167-8809(01)00276-6.
Chena, H., Zhu, T., Krotta, M., Calvo, J.F., Ganesh, S.P., Makot, I., 2013. Measurement and evaluation of livelihood assets in sustainable forest commons governance. Land Use Pol. 30, 908–914. https://doi.org/10.1016/j.landusepol.2012.06.009.
Clough, Y., Barkmann, J., Juhrbandt, J., Kessler, M., Wanger, T.C., Anshary, A., Buchori, D., Cicuzza, D., Darras, K., Putra, D.D., Erasmi, S., Pitopang, R., Schmidt, C., Schulze, C.H., Seidel, D., Steffan-Dewenter, I., Stenchly, K., Vidal, S., Weist, M., Wielgoss, A.C., Tscharntke, T., 2011. Combining high biodiversity with high yields in tropical agroforests. Proc. Natl. Acad. Sci. U. S. A. 2, 5–8. https://doi.org/10.1073/pnas.1201800109.
DaMatta, F.M., 2004. Ecophysiological constraints on the production of shaded and unshaded coffee: a review. Field Crop. Res. 86, 99–114. https://doi.org/10.1016/j.fcr.2003.09.001.
De Beenhouwer, M., Aerts, R., Honnay, O., 2013. A global meta-analysis of the biodiversity and ecosystem service benefits of coffee and cacao agroforestry. Agric. Ecosyst. Environ. 175, 1–7. https://doi.org/10.1016/j.agee.2013.05.003.
de San Martín, Gobierno Regional, 2008. Climate Data San Martín. [WWW Document]. Perú. http://es.climate-data.org/, Accessed date: 2 March 2017.
Defries, R.S., Rudel, T., Uriarte, M., Hansen, M., 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. Nat. Geosci. 3, 178–181. https://doi.org/10.1038/ngeo756.
DFID, 1999. Sustainable livelihoods guidance sheet. https://doi.org/10.1002/smj.
Eakin, H., 2005. Institutional change, climate risk, and rural vulnerability: Cases from Central Mexico. World Dev. 33, 1923–1938. https://doi.org/10.1016/j.worlddev.2005.06.005.
Eakin, H., Winkels, A., Sendzimir, J., 2009. Nested vulnerability: exploring cross-scale linkages and vulnerability teleconnections in Mexican and Vietnamese coffee systems. Environ. Sci. Policy 12, 398–412. https://doi.org/10.1016/j.envsci.2008.09.003.
Eakin, H., Tucker, C.M., Castellanos, E., Diaz-porras, R., Barrera, J.F., Morales, H., 2014. Adaptation in a multi-stressor environment: perceptions and responses to climatic and economic risks by coffee growers in Mesoamerica. Environ. Dev. Sustain. 123–139. https://doi.org/10.1007/s10668-013-9466-9.
Edwards-Jones, G., 2006. Modelling farmer decision-making: concepts, progress and challenges. Anim. Sci. 82, 783–790. https://doi.org/10.1017/ASC2006112.
Ellis, F., 2000. Rural Livelihoods and Diversity in Developing Countries. Oxford University Press, Oxford, England.
Fang, Y.P., Fan, J., Shen, M.Y., Song, M.Q., 2014. Sensitivity of livelihood strategy to livelihood capital in mountain areas: empirical analysis based on different settlements in the upper reaches of the Minjiang River, China. Ecol. Indicat. 38, 225–235. https://doi.org/10.1016/j.ecolind.2013.11.007.
Feola, G., Binder, C.R., 2010. Towards an improved understanding of farmers' behaviour: the integrative agent-centred (IAC) framework. Ecol. Econ. 69, 2323–2333. https://doi.org/10.1016/j.ecolecon.2010.07.023.
Feola, G., Lerner, A.M., Jain, M., Montefrio, M.J.F., Nicholas, K. a., 2015. Researching farmer behaviour in climate change adaptation and sustainable agriculture: Lessons learned from five case studies. J. Rural Stud. 39, 74–84. https://doi.org/10.1016/j.jrurstud.2015.03.009.
Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. Nature 478, 337–342. https://doi.org/10.1038/nature10452.
Fox, J., Weisberg, S., Adler, D., Bates, D., Baud-Bovy, G., Ellison, S., Firth, D., Friendly, M., Gorjanc, G., Graves, S., Heiberger, R., Laboissiere, R., Monette, G., Murdoch, D., Nilsson, H., Ogle, D., Ripley, B., Venables, W., Winsemium, D., Zeileis, A., R-Core, 2016. An R Companian to Applied Regression.
Fraley, C., Raftery, A.E., Scrucca, L., Murphy, T.B., Fop, M., 2017. Mclust -Gaussian Mixture Modelling for Model-Based Clustering, Classification and Density Estimation.
Frank, E., Eakin, H., López-Carr, D., 2011. Social identity, perception and motivation in adaptation to climate risk in the coffee sector of Chiapas, Mexico. Glob. Environ. Chang. 21, 66–76. https://doi.org/10.1016/j.gloenvcha.2010.11.001.
Garnett, S.T., Sayer, J., Du Toit, J., 2007. Improving the effectiveness of interventions to balance conservation and development: a conceptual framework. Ecol. Soc. 12.
Gliessman, S.R., 1992. Agroecology in the tropics: Achieving a balance between land use and preservation. Environ. Manag. 681–689.
Hernández-Martínez, G., Manson, R.H., Hernández, A.C., 2009. Quantitative classification of coffee agroecosystems spanning a range of production intensities in central Veracruz, Mexico. Agric. Ecosyst. Environ. 134, 89–98. https://doi.org/10.1016/j.agee.2009.05.020.
Imbach, P., Fung, E., Hannah, L., Navarro-Racines, C.E., Roubik, D.W., Ricketts, T.H., Harvey, C.A., Donatti, C.I., Läderach, P., Locatelli, B., Roehrdanz, P.R., 2017. Coupling of pollination services and coffee suitability under climate change. Proc. Natl. Acad. Sci. Unit. States Am. 114https://doi.org/10.1073/pnas.1617940114. 10438–10422.
Jackson, D., Skillman, J., Vandermeer, J., 2012. Indirect biological control of the coffee leaf rust, Hemileia vastatrix, by the entomogenous fungus Lecanicillium lecanii in a complex coffee agroecosystem. Biol. Control 61, 89–97. https://doi.org/10.1016/j.biocontrol.2012.01.004.
Jezeer, R.E., Santos, M.J., Boot, R.G.A., Junginger, M., Verweij, P.A., 2018. Effects of shade and input management on economic performance of small-scale Peruvian coffee systems. Agric. Syst. 162, 179–190. https://doi.org/10.1016/j.agsy.2018.01.014.
Jha, S., Bacon, C.M., Philpot, S.M., Ernesto Mendez, V., Laderach, P., Rice, R.A., 2014. Shade coffee: update on a disappearing refuge for biodiversity. Bioscience 64, 416–428. https://doi.org/10.1093/biosci/biu038.
Jonsson, M., Raphael, I.A., Ekbom, B., Kyamanywa, S., Karungi, J., 2015. Contrasting effects of shade level and altitude on two important coffee pests. J. Pest. Sci. 2004 (88), 281–287. https://doi.org/10.1007/s10340-014-0615-1.
Kassambara, A., Mundt, F., 2017. Package "Factorextra": Extract and Visualize the Results of Mutivariate Data Analyses.
Larrea, C., Eckhardt, K., Arana, A., 2014. El impacto económico del cambio climático en la selva alta para el cultivo del café. pp. 1–22.
Laurance, W.F., 1999. Effects on the tropical deforestation crisis. Biol. Conserv. 91, 109–117. https://doi.org/10.1016/S0006-3207(99)00088-9.
Levine, S., 2014. How to Study Livelihoods: Bringing a Sustainable Livelihoods Framework to Life (No. 22). (London, United Kingdom).
Lin, B.B., 2007. Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. Agric. For. Meteorol. 144, 85–94. https://doi.org/10.1016/j.agrformet.2006.12.009.
Mas, A., Dietsch, T., 2003. An index of management intensity for coffee agroecosystems to evaluate butterfly species richness. Ecol. Appl. 13, 1491–1501. https://doi.org/10.1890/01-5229.
McGregor, M.J., Rola-Rubzen, M.F., Murray-Prior, R., 2001. Micro and macro-level approaches to modelling decision making. Agric. Syst. 2001, 63–83.
Mercer, D.E., 2004. Adoption of agroforestry innovations in the tropics: a review. Agrofor. Syst. 61–62, 311–328. https://doi.org/10.1023/B:AGFO.0000029007.85754.70.
Morton, J.F., 2007. The impact of climate change on smallholder and subsistence agriculture. Proc. Natl. Acad. Sci. Unit. States Am. 104, 19680–19685. https://doi.org/10.1073/pnas.0701855104.
Muschler, R.G., 2001. Shade improves coffee quality in a sub-optimal coffee-zone of Costa Rica. Agrofor. Syst. 51, 131–139. https://doi.org/10.1023/A:1010603320653.
Padrón, B.R., Burger, K., 2015. Diversification and labor market effects of the Mexican coffee crisis. World Dev. 68, 19–29. https://doi.org/10.1016/j.worlddev.2014.11.005.
Patt, A., Schroter, D., 2008. Perceptions of climate risk in Mozambique: implications for the success of adaptation strategies. Glob. Environ. Chang. 18, 458–467. https://doi.org/10.1016/j.gloenvcha.2008.04.002.
Paul, F., Ruf, F., Yoddang, 2013. Diversification et cycle de cultures pérennes à Aceh, Indonésie. In: Ruf, F., Schroth, G. (Eds.), Cultures Pérennes Tropicales: Enjeux Économiques et Écologiques de La Diversification. Éditions Quae, Versailles, France, pp. 265–279.
Perfecto, I., Rice, R.A., Greenberg, R., van der Voort, M.E., 1996. Shade coffee: a disappearing refuge for biodiversity. Bioscience 46 (8), 598–608.
Perfecto, I., Vandermeer, J., 2015. Coffee Agroecology- A New Approach to Understanding Agricultural Biodiversity, Ecosystem Services and Sustainable Development. Routledge, New York.
Quiroga, S., Suárez, C., Solís, J.D., 2015. Exploring coffee farmers' awareness about climate change and water needs: smallholders' perceptions of adaptive capacity. Environ. Sci. Policy 45, 53–66. https://doi.org/10.1016/j.envsci.2014.09.007.
R Core Team, 2014. A language and environment for statistical computing. In: R

Foundation for Statistical Computing.
Rahman, S., 2003. Farm-level pesticide use in Bangladesh: Determinants and awareness. Agric. Ecosyst. Environ. 95, 241–252. https://doi.org/10.1016/S0167-8809(02)00089-0.
Rahn, E., Läderach, P., Baca, M., Cressy, C., Schroth, G., Malin, D., van Rikxoort, H., Shriver, J., 2014. Climate change adaptation, mitigation and livelihood benefits in coffee production: where are the synergies? Mitig. Adapt. Strategies Glob. Change 19, 1119–1137. https://doi.org/10.1007/s11027-013-9467-x.
Rodriguez, D., Cox, H., deVoil, P., Power, B., 2014. A participatory whole farm modelling approach to understand impacts and increase preparedness to climate change in Australia. Agric. Syst. 126, 50–61. https://doi.org/10.1016/j.agsy.2013.04.003.
Ruf, F., Schroth, G., 2015. Economics and ecology of diversification, economics and ecology of diversification: the case of tropical tree crops. https://doi.org/10.1007/978-94-017-7294-5.
Schroth, G., Ruf, F., 2014. Farmer strategies for tree crop diversification in the humid tropics. A review. Agron. Sustain. Dev. 34, 139–154. https://doi.org/10.1007/s13593-013-0175-4.
Scoones, I., 1998. Sustainable rural livelihoods a framework for analysis, analysis. https://doi.org/10.1057/palgrave.development.1110037.
Scoones, I., 2009. Livelihoods perspectives and rural development. J. Peasant Stud. 36, 171–196. https://doi.org/10.1080/03066150902820503.
Siebert, S.F., 2002. From shade- to sun-grown perennial crops in Sulawesi, Indonesia: implications for biodiversity conservation and soil fertility. Biodivers. Conserv. 11, 1889–1902. https://doi.org/10.1023/A:102080461.
Tucker, C.M., Eakin, H., Castellanos, E.J., 2010. Perceptions of risk and adaptation: coffee producers, market shocks, and extreme weather in Central America and Mexico. Glob. Environ. Chang. 20, 23–32. https://doi.org/10.1016/j.gloenvcha.2009.07.006.
Vargas, P., 2009. El Cambio Climático y Sus Efectos en el Perú. Banco Central de Reserva del Perú, Lima, Perú.
Vargas, C.D., Willems, M.C., 2017. Línea de base del sector café en el Perú - documento de trabajo. Programa de las Naciones Unidas para el Desarollo, Lima, Perú.
Waller, J.M., Bigger, M., Hillocks, R.J., 2007. World coffee production. In: Coffee Pests, Diseases and Their Management. CABI, Egham, Surrey, UK, pp. 17–33. https://doi.org/10.1079/9781845931292.0000.
Weber, J.G., 2011. How much more do growers receive for Fair Trade-organic coffee? Food Policy 36, 677–684. https://doi.org/10.1016/j.foodpol.2011.05.007.
Wollni, M., Brümmer, B., 2012. Productive efficiency of specialty and conventional coffee farmers in Costa Rica: accounting for technological heterogeneity and self-selection. Food Policy 37, 67–76. https://doi.org/10.1016/j.foodpol.2011.11.004.