Ecosystem Services 33 (2018) 44–58

Contents lists available at ScienceDirect

Ecosystem Services

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

Farmers show complex and contrasting perceptions on ecosystem services and their management

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ARTICLE INFO

Keywords:
Fuzzy cognitive maps
Agroecosystems
Agroecology
Biodiversity
Brazil

ABSTRACT

Agricultural systems are complex socio-ecological systems that are managed by farmers to achieve desired outcomes, including food production and other ecosystem services (ES). While farm management is a key factor for ES provision, farmers may widely differ in their awareness, ambition and skills to manage their systems. Currently there is a lack of understanding of farmers' perception on ES, and how this is related to their management. We studied the management and perception of large scale farmers, conventional family farmers and agroecological family farmers in the Zona de Mata region in Brazil. Farmers were interviewed and constructed fuzzy cognitive maps (FCM) of their perception on ES. The FCM analysis revealed that in general, the perception of farmers on ES is highly complex and interconnected. Yet, agroecological family farmers showed a more complex perception on ES, which is associated with more diversified and autonomous agroecosystems. Both agroecological and conventional family farmers had a strong peasant identity, recognising more cultural ecosystem services than large scale farmers and relied more on production for consumption. Initiatives that aim to strengthen on-farm ecosystem services provision should be sensitive to farmer's perceptions and may need to consider using specific strategies for different farmer types.

1. Introduction

With the expansion of human-dominated land use (Foley et al., 2011), agroecosystems hold an increasing share of the global biodiversity (Baudron and Giller, 2014). This has also consequences for the associated provision of ecosystem services (ES), which are broadly defined as the benefits people obtain from nature (MEA, 2005). The ES framework can be useful to systematically identify the multiple benefits provided by agroecosystems, while accounting for the interests of different stakeholder groups, encompassing ecological and social dimensions and exploring the linkages between science, policy and practice (Braat and de Groot, 2012). According to the preferences and aspirations of social actors, the provision of particular ES can be recognised and prioritized (Lamarque et al., 2014, Cáceres et al., 2015). Since farmers are directly responsible for taking decisions and managing agroecosystems, strategies for promoting the delivery of multiple ES should consider their needs and perceptions to be socially acceptable and transformative (Duru et al., 2015; Bernués et al., 2016). Yet, farmers constitute a very diverse group of actors (Torquebiau et al., 2012) and their management is influenced by a myriad of factors, including assets, ambitions, social networks, policies, markets, but also by their understanding and perception of the functioning of their agroecosystem. Although farmer's mental constructions may have a great influence on their practices (Vuillot et al., 2016), little is known about farmer's perceptions of ES and how this is related to agroecosystem management (Lamarque et al., 2014; Smith and Sullivan, 2014; Lescourret et al., 2015).

Farmers often have deep experimental knowledge of their systems, in which multiple ES are managed simultaneously. This is challenging because of the many positive, negative and non-linear relationships among different ES and management practices (Lescourret et al., 2015). Managing multiple ES requires a knowledge-intensive, holistic approach that takes into account the interactions among economic, social, cultural and ecological aspects (Smith and Sullivan, 2014; Tancoigne et al., 2014). Although research efforts have increasingly focused on integrated assessments of ES bundles (Boerema et al., 2016; Costanza et al., 2017), the factors underlying the social-cultural valuing of multiple ES and their interactions remains underexplored (Cáceres et al., 2015; Costanza et al., 2017). The social-cultural

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https://doi.org/10.1016/j.ecoser.2018.08.006
Received 6 April 2018; Received in revised form 6 June 2018; Accepted 21 August 2018
Available online 31 August 2018

valuing is especially relevant for supporting, regulating and cultural ES, because these services are more difficult to quantify in economic terms (Chan et al., 2012) and their valuation can vary more strongly according to perceptions of social actors (Hein et al., 2016).

The study of farmers' perceptions of ES in relation to their management practices should take their personal aspirations, values and beliefs into account, as well as the functional and structural variables of the farm, such as production orientation and farm size (Vuillot et al., 2016). This requires methodologies that can capture the most important ES and their interactions according to farmers, as well as to identify relevant management and socio-ecological variables (Díaz et al., 2011; Bennett et al., 2015). Here we used fuzzy cognitive maps (FCM) as an integrated research tool to assess how farmers perceive and value the entire bundle of multiple and interconnected ES, and how this perception and valorisation influences their management of the agroecosystem. FCM is a semi-quantitative modelling tool that has been developed to assess and compare knowledge from non-technical experts (Özesmi and Özesmi, 2004) and has been successful in integrating social and ecological sciences (Kok, 2009; Papageorgiou and Salmeron, 2013; Jetter and Kok, 2014). FCM are simple to use in participatory settings (van Vliet et al., 2010), and suitable to deal with inherently complex and subjective concepts (Reyers et al., 2013; Chan et al., 2012).

The objectives of this study were (i) to understand farmers' perceptions on the management and provision of multiple ecosystem services, (ii) to contrast perceptions among farmers belonging to different farm types, and (iii) to explore the linkages between farmers' perceptions, agrobiodiversity and production orientation. For this purpose, the FCM was combined with a farm characterization and on-farm assessment of agrobiodiversity indicators to link farmers' perceptions with farm structural and functional variables.

2. Material and methods

2.1. Study area

The study was conducted in the Zona da Mata region, in the South-Eastern part of Minas Gerais, Brazil. It is located in the Atlantic rainforest biome, which is considered the fifth biodiversity hotspot in the world, hosting many unique endemic and threatened species (Myers et al., 2000). The landscape is hilly and is commonly described as a 'sea of hills', because of its geomorphology (Greenfield, 1977). In the eighteenth century, the existing indigenous communities in Zona da Mata faced several conflicts, were colonized and nearly extinguished by the Portuguese invaders. After the colonization, in the nineteenth century, Brazilian aristocratic landlords from other parts of the country were granted great portions of land and established, among other crops, coffee plantations based on slave labour. In the initial growing years, coffee was intercropped with annual crops, such as maize, rice and beans. Since the abolishment of slavery, diverse social dynamics led to the division of land, mainly due to heritage processes as well as land acquisition by landless rural workers (Valverde, 1958). Nowadays, there is a predominance of family farmers, who diversify the use and management of the land in the Zona da Mata. As a result, the region consists of a mosaic of different land uses: pasture, which is often extensive and degraded; coffee, the most important and labour intensive cash crop, commonly intercropped with maize, beans, cassava and other crops; and forest fragments, often located in protected or less accessible areas. Although homegardens usually only occupy small areas of the farm, they are important for the food sovereignty of the families and host a diversity of plant and animal species (Oliveira, 2015). There are a variety of national and state public policies targeting family farmers that provide access to credits, market, land and education. However, the development of these policies is challenging and their effectiveness is limited because of bureaucracy, limited involvement of farmers in the creation process, and uncertainty about the continuity of these policies due to governmental changes.

The study was conducted in the three municipalities Araponga, Divino and Espera Feliz, which connect two nature conservation areas: the state park "Serra do Brigadeiro" and the National Park "Caparaó" (Fig. 1). The municipalities have a unique history of participatory

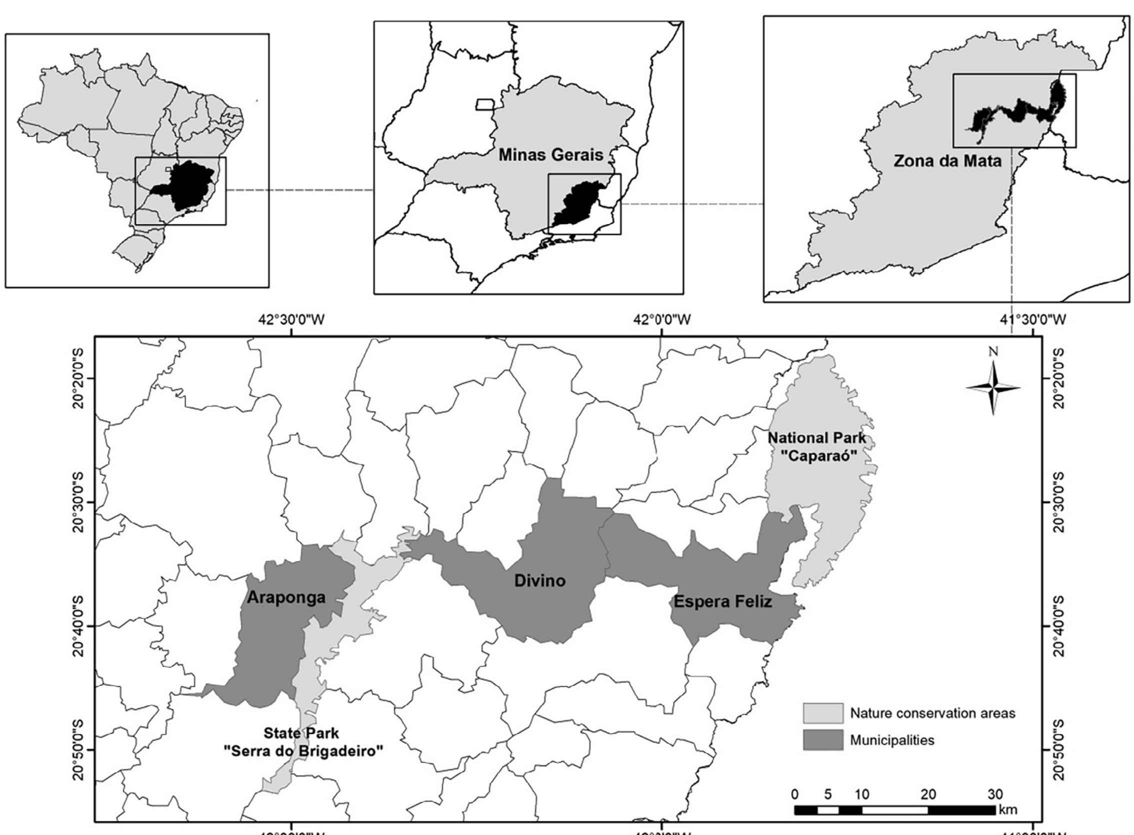


Fig. 1. Map of studied municipalities in Zona da Mata and areas of nature conservation.

partnerships between the University of Viçosa (UFV), the socio-environmental NGO Centro de Tecnologias Alternativas da Zona da Mata (CTA-ZM), and family farmers' organisations, which along with social and political movements, have resulted in a strong agroecological awareness among family farmers (Cardoso et al., 2001; Cardoso and Mendes, 2015).

2.2. Subject definition and selection

Three farmer types were selected for this study: agroecological family farmers, conventional family farmers (including sharecroppers), and large scale farmers (Teixeira et al., unpublished). Agroecological family farmers did not use synthetic pesticides and were active in social organizations (e.g. unions). Besides selling their coffee to retailers, agroecological family farmers often have access to alternative markets, such as an institutional market supported by public policies, self-organised market fairs, direct selling to the consumers and in small shops. Conventional family farmers mainly sell their coffee to retailers as their main source of income and rely strongly on the use of external inputs. In conventional and agroecological family farms (i) farm labour and management was predominantly provided by family members; (ii) the farm area was less than 96 hectares; and (iii) the main family income came from rural activities (according to the Brazilian law n°11.326 (National Policy on Family Farming and Rural Family Enterprises, 2006)). Public policy does not recognise differences between conventional and agroecological family farmers, unless their products are certified as organic. Large scale farms are characterized by farm sizes exceeding 96 ha, reliance on contracted labour and a strong market-orientation. Coffee is managed intensively with high use of inputs and pasture is managed more extensively.

Farmers were selected for interviews using snowball sampling (Lamarque et al., 2011; Klingen et al., 2012), for which we received the first contacts from farmer unions. Once we had a starting point in a municipality, we continued asking farmers to connect us with nearby people in the community representing our focal farmer categories. To avoid remaining stuck in a single social network, we also randomly visited farmers without prior connections. This procedure resulted in the selection of ten agroecological family, nine conventional family and five large scale farmers, which approximately represent the different categories of farmers in the region. The levelling off of new number of factors mentioned per interview across the farmer types confirmed that the sample size of agroecological and conventional farmers were adequate, while this was not the case for large scale farmers (Appendix A) (Özesmi and Özesmi, 2004). However, the relatively low number of large scale farmers reflect the fact that this group encompasses only 18.4% of farmers in the Zona da Mata (IBGE, 2006).

2.3. Interviews and fuzzy cognitive map construction

We conducted individual interviews with farmer families because farm management decisions are usually taken in the family setting. The interviews were centred around the question: "what benefits do you obtain from nature?" We used this starting point to construct a FCM of the farmer's belief system, consisting of key factors that drive a system and arrows that represent perceived causal relationships among factors. Arrows are weighted with a score representing the strength of associations often linguistically assessed by stakeholders (Papageorgiou and Salmeron, 2013).

The interview consisted of five steps to guarantee that all relevant factors (nodes of the network) were included and that both direct and indirect benefits and beneficial and detrimental effects were addressed.

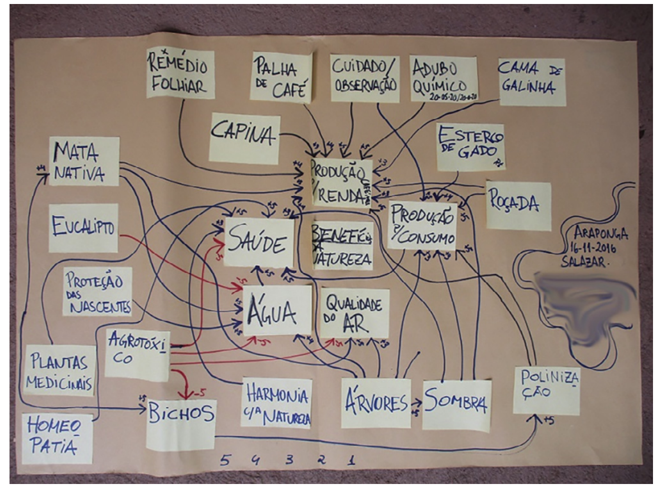


Fig. 2. Example of a fuzzy cognitive map constructed together with an agroecological farmer in Araponga on 16-11-2016 (in colour). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In the first step, an A0 sheet of paper was presented to farmers with a post-it in the centre stating 'Nature's benefits'. Farmers were asked to state what direct benefits they got from their land and nature. The keywords were identified by the facilitator, written on additional post-its and placed on the sheet (Fig. 2). This included direct services such as production for consumption and the market, water and autonomy. In the second step, farmers were asked what is needed to provide these benefits. This resulted in additional factors placed on the map, and connections between the factors on the post-its were drawn to indicate the associations with other factors. In the third step farmers were asked about negative influences on the provision of ES, if these had not already been mentioned during steps one and two. The fourth step involved the quantification of the strength of the connections (weight of arrows). Farmers could choose from a positive or negative value ranging from 1 to 5, where 1 is a weak influence and 5 is a strong influence (Fig. 2). In the fifth step farmers were asked whether there were still factors missing and whether the map represented their personal vision. If this was not the case yet, additional amendments were made until the map reflected the farmers' perception.

The interviews were complemented by an assessment of farm structural and functional variables, including: (1) the number of crop types used for self-consumption and for the market, where vegetable gardens were counted as a single unit; (2) the number of different products sold on the market; (3) number of coffee plants, (4) land area (ha), and (5) the number of tropical livestock units (TLU). For the number of TLU we only considered cattle, and not poultry. We also recorded the number of participants and the duration of the interviews.

2.4. Fuzzy cognitive map analysis

Fuzzy cognitive maps (FCM) were constructed together with farmers in each farm and analysed by assessing the following FCM indices: number of factors (nodes), connections (arrows) and the type of factors (transmitter, receiver and ordinary variables). Transmitter variables only have outgoing arrows, indicating a forcing factor, which cannot be influenced by other factors in the system. Receiver variables only have ingoing arrows, indicating that these factors can be controlled by other factors in the system. Ordinary variables have both in-and outgoing arrows, indicating factors that can both be influenced and have an influence on other factors in the system (Özesmi and Özesmi, 2004). The FCM indices were calculated using graph theory (Özesmi and Özesmi, 2004). The cognitive map data were coded into adjacency matrices in the form A(D) = [aij], where the elements aij represent the strength of a connection from vertex i to vertex j, with zero values meaning no connection (see Appendix B for an example). The identified factors (nodes, variables v) are both listed on the vertical axis (vi) and on the horizontal axis (vj). The strengths (weights) of the arrows on the A0 sheets were rescaled to a range from 0.1 to 0.9 (positive connections) and −0.1 to −0.9 (negative connections) for input in the FCM model (Kok, 2009). The centrality of factors was determined by the sum of absolute weights of in- and outgoing arrows. In addition, factors were categorised as direct ES, intermediate ES, ecosystem component, external input, management practice or socioeconomic aspect. Direct ES are final services from which humans can directly benefit, which includes provisioning and cultural ES, while intermediate ES include regulating and supporting ES, which have a mediating function to generate direct ES.

The FCM from individual farmers were combined to obtain one social FCM for each farmer type (agroecological family, conventional family and large scale farmers) and one social FCM at regional level, including all 24 farmers. The social FCM is created by merging the factors and summing the connections between the same factors of all farmers in the group. The weight of the connections was divided by the number of farmers per group to derive mean centrality scores. Positive and negative connections between the same factors cancelled each other out. To improve the visual presentation of the social FCM (Figs. 3a–c), factors were only included when mentioned by at least two farmers, or had a weighted centrality score higher or equal to 0.50. The centrality scores of the factors (nodes) and relative weighs of connections (arrows) derived from the social maps are mentioned throughout the text. Statistical analyses were based on all factors and connections of the social FCM, which are not necessarily depicted in Fig. 3.

2.5. Statistical analysis

To assess differences on perceptions and agroecosystem management among farmer types, FCM indices and farm structural and functional variables were analysed with parametric and non-parametric statistical tests. ANOVA was used for normally distributed data with equal variances, and otherwise by Kruskal–Wallis tests when normality

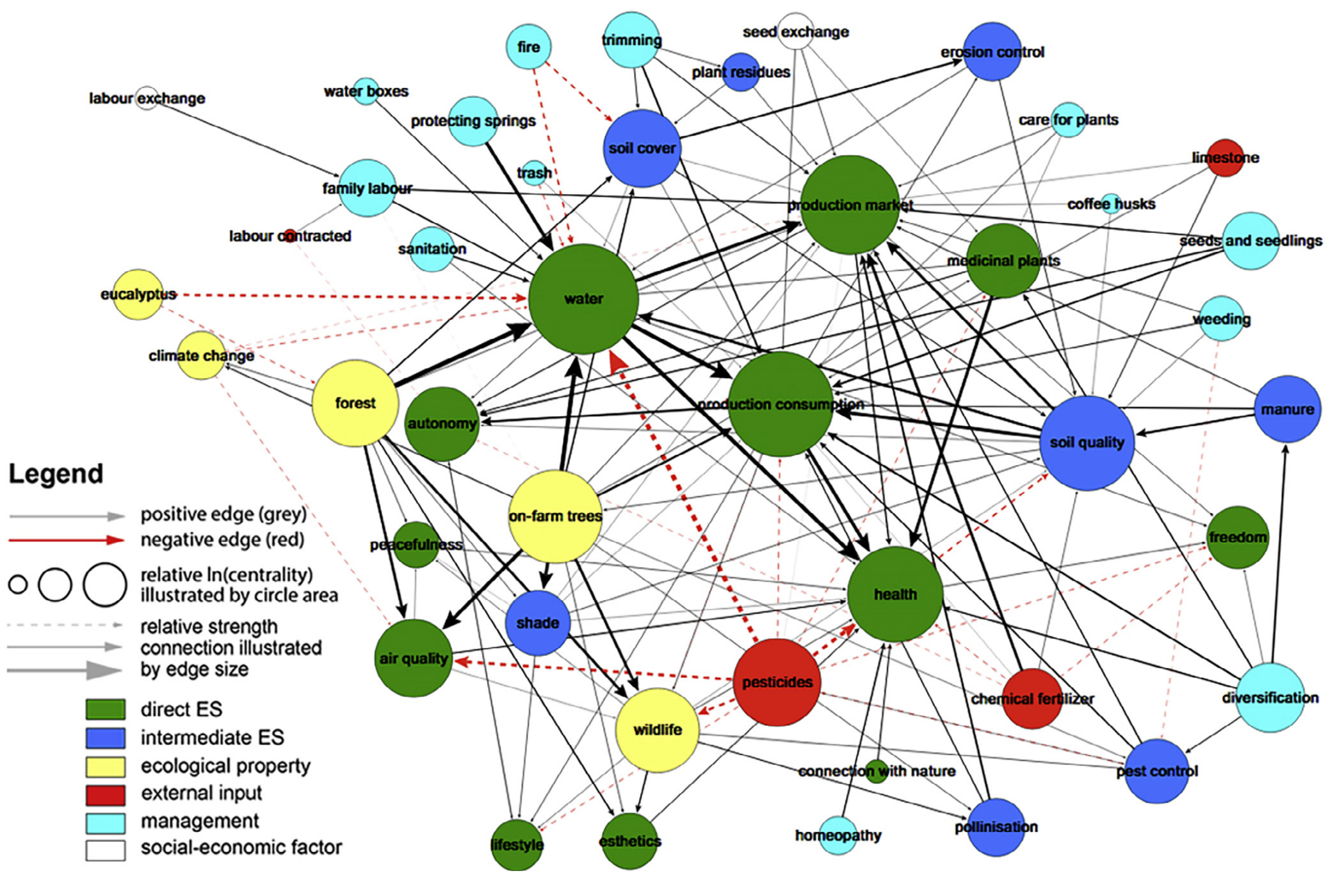


Fig. 3a. Social map of agroecological family farmers ($n = 10$). Centrality is the sum of absolute weights of in- and outgoing connections. For graphical representation only factors that were mentioned by a minimum of two farmers and had a centrality score ≥0.50 are shown (in colour). The size of the circles indicates the relative centrality score of each factor, the thickness of the arrows represents the relative strength of the connection, and arrow colours indicate positive (grey) or negative (red) connections. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

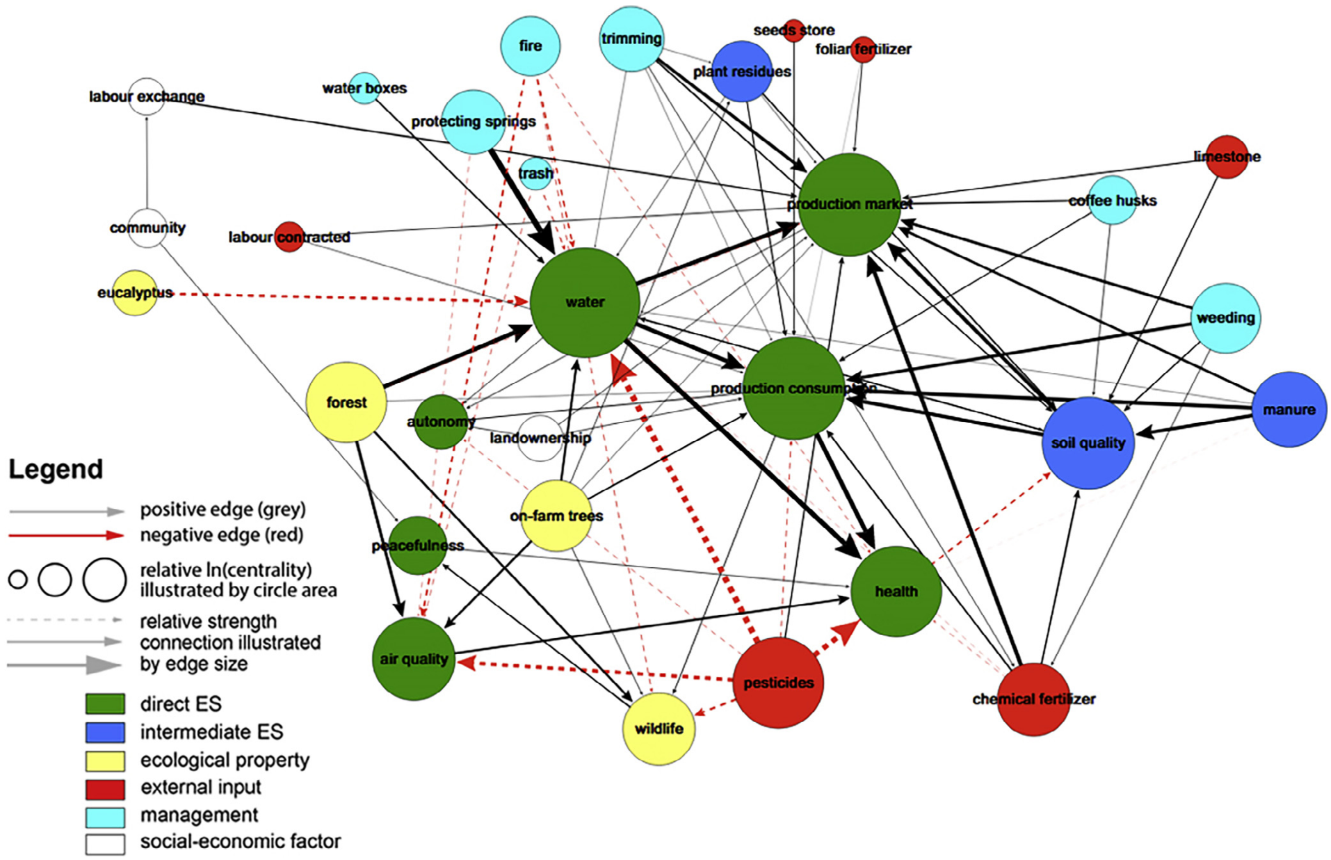


Fig. 3b. Social map of conventional family farmers (n = 9). Centrality is the sum of absolute weights of in- and outgoing connections. For graphical representation only factors that were mentioned by a minimum of two farmers and had a centrality score ≥0.50 are shown (in colour). The size of the circles indicates the relative centrality score of each factor, the thickness of the arrows represents the relative strength of the connection, and arrow colours indicate positive (grey) or negative (red) connections. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

criteria were not met. Normality was assessed using a Shapiro–Wilk test with 0.05 significant levels and a Q-Q plot; equal variances were assessed using Levene's test. Significant ANOVA tests were followed up with a pairwise comparisons between groups using a Games-Howell post hoc test, recommended for unequal variances and group sizes (Field, 2013). Significant Kruskal–Wallis tests were further analysed by pairwise comparisons using a Dunn test with a Benjamini & Hochberg (BH) adjustment for false discovery rate control (Benjamini and Hochberg, 1995). We used logistic regression analysis for binomially distributed variables, which were followed by a post hoc test with a Bonferroni adjustment. Factors that were significant at the $P < 0.10$ level were further analysed using a rotated Principal Components Analysis (PCA) to assess the associations with farm structural and functional variables. A Pearson's correlation matrix was computed to exclude any cases of multicollinearity (R > 0.8) or singularity (majority of R < 0.3). The number of extract components were based on the screen plot (see Appendix C) and a minimum of three communalities with a score > 0.7 (Appendix C) (Field, 2013). We use a significance level of $P < 0.05$ unless otherwise indicated and report p-values of post hoc tests throughout the text. The statistical analyses were conducted in SPSS v.23.0 (Mac) and R 3.3.2 (Mac).

3. Results

In 24 interviews farmers identified a total of 104 different factors and 363 connections (Appendix D). The factors were categorised as direct ES (18), intermediate ES (16), ecosystem properties (13), external inputs (10), management practices (31) and socioeconomic aspects (16). The FCM highlighted that agroecological family, conventional family and large scale farmers differed in their perceptions of the agroecosystem. Agroecological family farmers identified significantly more connections per FCM than conventional family and large scale farmers (p = 0.006, and p = 0.005, respectively; Table 1) and more ordinary variables (i.e. factors with both in and out-going arrows; p = 0.005, and p = 0.003, respectively; Table 1), indicating that agroecological family farmers have more complex perception of their system. Agroecological family farmers mentioned significantly fewer external inputs than conventional family (p = 0.023) and large scale farmers (p = 0.007; Table 1). Both agroecological and conventional family farmers recognised significantly more direct ES than large scale farmers (p = 0.002, and p = 0.007, respectively; Table 1). No significant differences were found among farmer types for number of ecosystem components, management and socioeconomic factors.

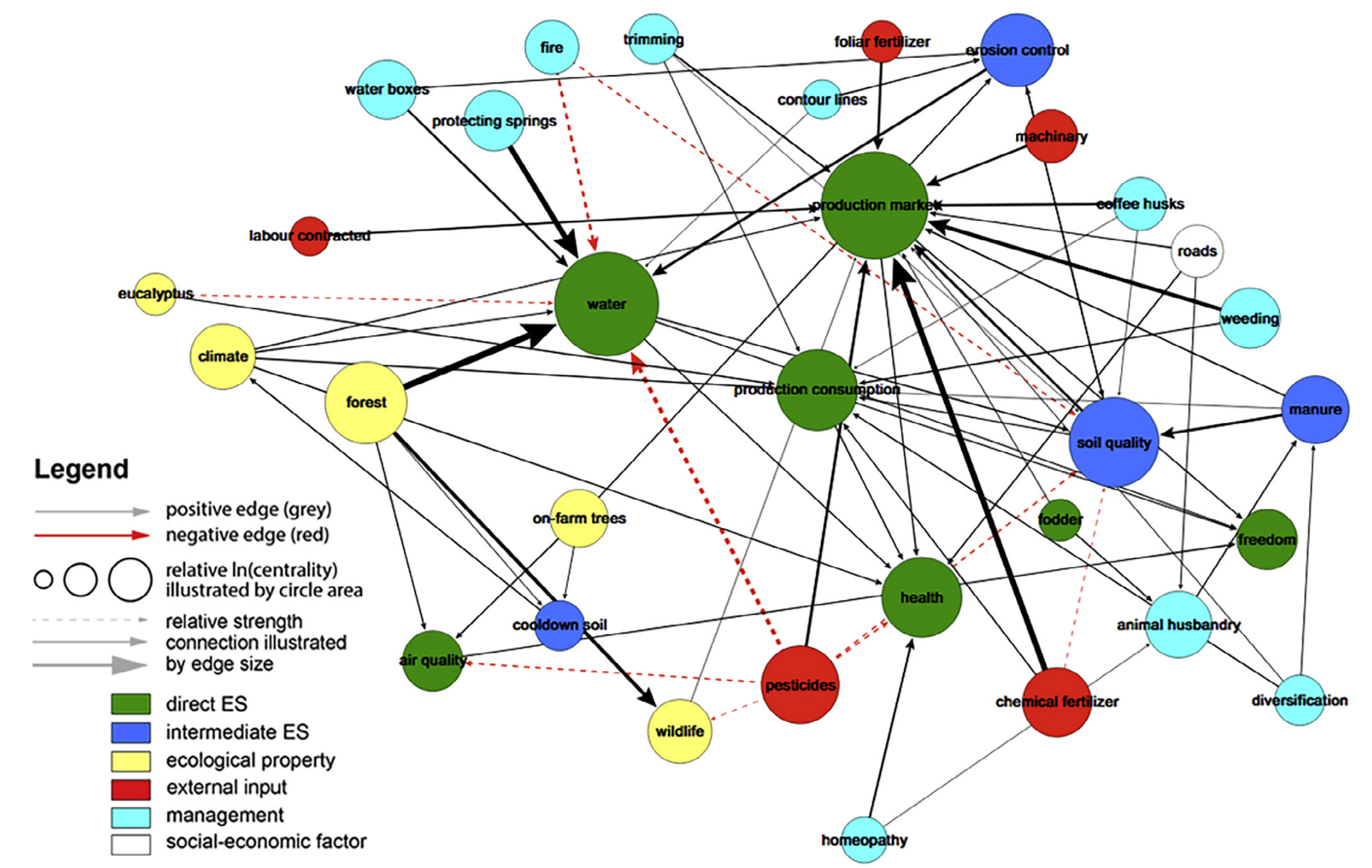


Fig. 3c. Social map of large farmers (n = 5). Centrality is the sum of absolute weights of in- and outgoing connections. For graphical representation only factors that were mentioned by a minimum of two farmers and had a centrality score ≥0.50 are show (in colour). The size of the circles indicates the relative centrality score of each factor, the thickness of the arrows represents the relative strength of the connection, and arrow colours indicate positive (grey) or negative (red) connections. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1

Overview results FCM indices, number of factors per category and additional indicators between farm types. · Marginally significant at p < .1; *Significant at p < .05; **Significant at p < .005.

	Statistical test	p-value	Agroecological (n = 10) $\bar{x}$ ± SE	Conventional (n = 9) $\bar{x}$ ± SE	Large farmer (n = 5) $\bar{x}$ ± SE
Interview time (minutes)	Kruskal-Wallis	0.282	64 ± 4.4	60 ± 4.7	47 ± 4.0
Factors (nr.), N	ANOVA	0.099·	22.7 ± 1.6	19.8 ± 1.8	21.2 ± 1.2
Connections (nr.), C	Kruskal-Wallis	0.004**	37.0 ± 2.1^{a}	29.3 ± 2.3^{b}	26.2 ± 2.2^{b}
Transmitter variables (nr.), T	Kruskal-Wallis	0.093·	11.5 ± 1.7	12.0 ± 1.7	14.4 ± 0.9
Receiver variables (nr.), R	Kruskal-Wallis	0.976	2.7 ± 1.3	2.8 ± 1.2	2.4 ± 0.9
No. of ordinary variables, O	Kruskal-Wallis	0.002**	8.5 ± 1.6^{a}	5.0 ± 1.0^{b}	3.3 ± 1.3^{b}
Direct ES (nr.)	Kruskal-Wallis	0.005**	6.20 ± 0.42^{a}	5.67 ± 0.26^{a}	3.40 ± 0.51^{b}
Intermediate ES (nr.)	Kruskal-Wallis	0.058·	3.40 ± 0.69	1.33 ± 0.37	2.40 ± 0.68
Ecosystem component (nr.)	Kruskal-Wallis	0.337	2.70 ± 0.40	2.11 ± 0.26	2.60 ± 0.25
Management (nr.)	Kruskal-Wallis	0.385	6.80 ± 0.76	6.22 ± 0.74	7.80 ± 0.20
Socioeconomic (nr.)	Kruskal-Wallis	0.944	1.20 ± 0.51	1.00 ± 0.37	1.00 ± 0.32
External input (nr.)	Kruskal-Wallis	0.010*	2.40 ± 0.27^{a}	3.44 ± 0.34^{b}	4.00 ± 0.32^{b}
Crop diversity (nr.)	ANOVA	0.008*	19.9 ± 3.3^{a}	9.1 ± 1.5^{b}	8.2 ± 2.4^{b}
Types of products sold	Kruskal-Wallis	0.013*	11.7 ± 4.5^{a}	1.44 ± 0.9^{b}	1.8 ± 0.6^{ab}
Total number of coffee plants (nr.)	Kruskal-Wallis	0.004**	11,560 ± 99.9^{a}	9,056 ± 67.0^{a}	100,000 ± 265.2^{b}
Farm size (ha)	Kruskal-Wallis	0.003**	9.0 ± 2.9^{a}	5.2 ± 1.8^{a}	107.6 ± 9.3^{b}
Tropical Livestock Unit, TLU	Kruskal-Wallis	0.003**	3 ± 1.3^{a}	4.6 ± 2.0^{a}	131.6 ± 66.1^{b}

The analysis of farm structural and functional variables showed that agroecological family farmers had a significantly higher number of crops than large scale farmers (p = 0.023) and conventional family farmers (p = 0.024), and also sold significantly more products than conventional farmers (p = 0.005; Table 1). Yet, the number of products sold by agroecological and large scale farmers was not significantly different (Table 1).

The PCA indicated a relatively clear grouping of agroecological family, conventional family and large scale farms (Fig. 4). The first PCA axis explained 31% of the total variation, and was strongly correlated to the number of factors mentioned in the FCM, crop diversity, products sold and trees benefits (R > 0.60; Appendix C). This axis can be interpreted as complexity of perception and farming systems, with agroecological farmers on the right and conventional farmers on the left side of the spectrum. The second axis explained 26% of the total variation and separated large farmers from family farmers. This axis can be

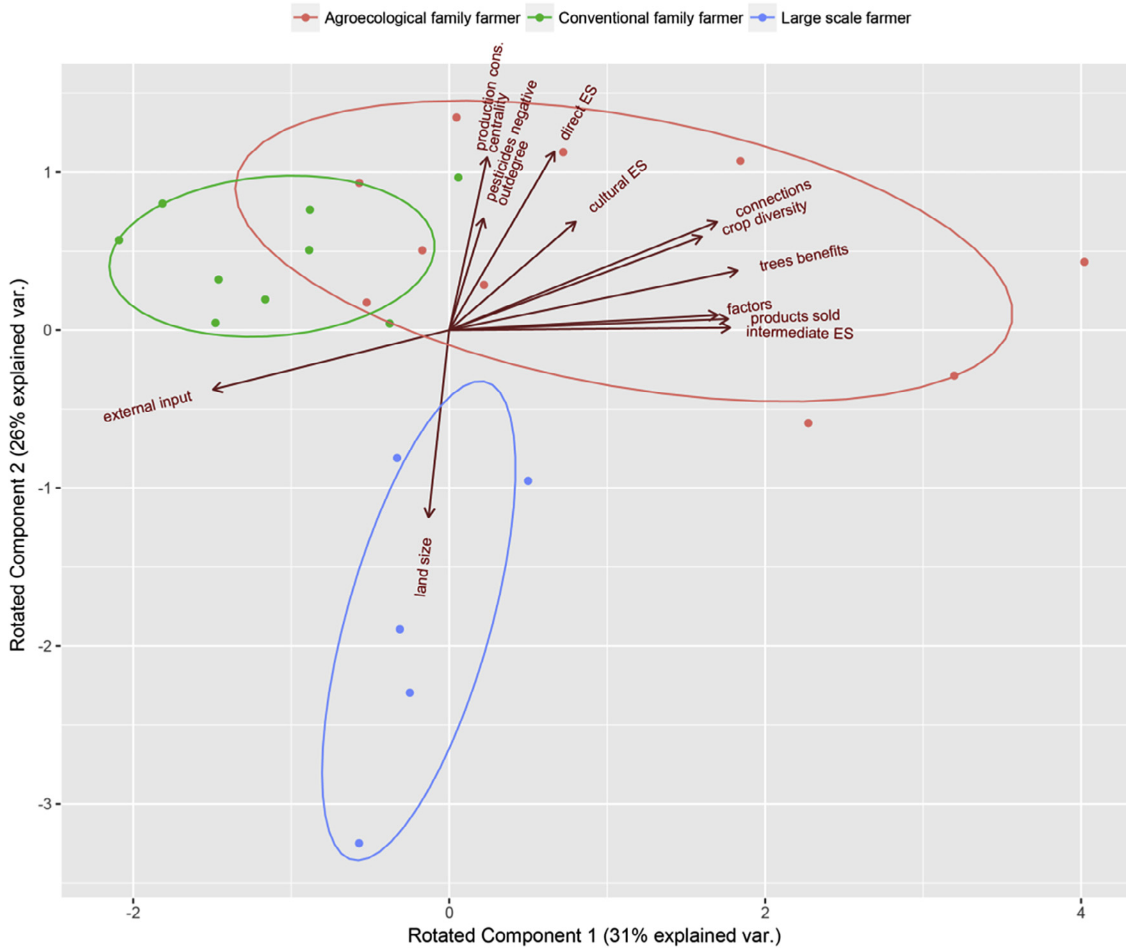


Fig. 4. Rotated PCA of all (marginally) significant results from the fuzzy cognitive maps indicators, agrobiodiversity indicators and farm size. Factors with multicollinearity ($R > 0.8$) or singularity (majority of $R < 0.3$) were excluded from the analysis.

interpreted as farm size, with family farming along the upper end and large scale farming along the lower end of the spectrum.

Interpretation of social FCM per farm type

The FCM revealed seven major themes that are detailed below (Table 1 and 2, Figs. 3a–c): importance of water, role of trees, pesticides, peasant farming (labour and food sovereignty), cultural ES, ecosystem components and intermediate services.

3.1. Importance of water

Water was mentioned by all 24 farmers, and it was the most central factor for agroecological and conventional family farmers, and the second most central factor for large scale farmers. There has been a long drought from 2012 to 2016, resulting in springs drying up and reduced yields. This finding shows the importance and the dependence of farmers on water as a primary ES. There was a significant difference between family (agroecological and conventional) farmers and large scale farmers in how water is perceived to affect other factors in the

Table 2
Summary of statistics used for the interpretation of social maps per farm type. Centrality is the sum of absolute weights of in- and outgoing connections (see Fig. 4).· Marginally significant at $p < .1$; *Significant at $p < .05$; **Significant at $p < .005$.

FCM interpretation	Statistical test	p-value	Agroecological ($n = 10$) $\bar{x} \pm$ SE	Conventional ($n = 9$) $\bar{x} \pm$ SE	Large farmer ($n = 5$) $\bar{x} \pm$ SE
Water (centrality)	ANOVA	0.976	6.56 ± 0.52	6.33 ± 0.52	4.90 ± 0.85
Water considered as an ordinary variable (yes/no)	Logistic regression	0.015*	90%	100%	40%
Trees (centrality)	Kruskal-Wallis	0.030*	3.17 ± 0.60^{a}	1.18 ± 0.48^{b}	0.64 ± 0.40^{b}
Benefits from trees (nr.)	Kruskal-Wallis	0.017*	4.10 ± 0.77^{a}	1.22 ± 0.49^{b}	0.80 ± 0.49^{b}
Pesticides (negative outdegree)	Kruskal-Wallis	0.047*	−2.59 ± 0.24^{a}	−2.61 ± 0.23^{a}	−1.18 ± 0.49^{b}
Pesticides (positive outdegree)	Kruskal-Wallis	0.018*	0.07 ± 0.05^{a}	0.17 ± 0.18^{ab}	0.38 ± 0.27^{b}
Production consumption (centrality)	Kruskal-Wallis	0.052·	5.14 ± 0.73^{a}	4.56 ± 0.40^{ab}	1.78 ± 1.16^{b}
Cultural ES (nr.)	Kruskal-Wallis	0.043*	1.60 ± 0.22^{a}	1.00 ± 0.29^{ab}	0.40 ± 0.25^{b}
Forest (centrality)	Kruskal-Wallis	0.745	2.24 ± 1.85	1.76 ± 1.02	1.86 ± 0.35
Wildlife (centrality)	Kruskal-Wallis	0.323	2.00 ± 0.52	1.22 ± 0.48	0.84 ± 0.38

system (logistic regression, Table 2). Ninety-five percent (18/19) of family farmers considered water to be an ordinary variable (having both in- and outgoing arrows), compared to 40% (2/5) of large farmers. The other three large farmers consider water as a receiver variable, which has no direct influence on other factors in the system. Based on the community representation of all farmers, the five most important factors that positively influenced water were forest (a relative weight of 0.65), protecting springs (0.64), trees (0.35), soil quality (0.21) and water boxes used to collect water (0.21). These factors represent 74% of the total positive indegree of water (the sum of absolute weights of positive ingoing arrows). The three strongest negative factors influencing the availability and/or quality of water were pesticides (−0.67), *Eucalyptus* trees (−0.28) and fire (−0.22). These factors represent 72% of the total negative indegree of water. Water is considered most important for health (relative weight 0.52), production for consumption (0.43) and production for the market (0.40), representing 80% of the total outdegree of water (the sum of absolute weights of outgoing arrows).

3.2. Role of trees

The factor "trees" include all trees in and surrounding arable fields and homegardens. Trees were mentioned by 15 out of the 24 farmers. There was a significant difference regarding the role of trees between farmer types. The centrality of trees is higher for agroecological family farmers than for conventional family ($p = 0.036$) and large scale farmers ($p = 0.021$). Agroecological family farmers also recognised more benefits from trees than conventional family ($p = 0.0127$) and large scale farmers do ($p = 0.025$; Table 2). This difference highlights the perceived multi-functionality of trees in agroecosystems by agroecological family farmers. For instance, the benefit of shade provided by trees was only mentioned by agroecological family farmers, and the benefit of trees on water, production for consumption and wildlife was only recognised by agroecological and conventional family farmers, but not by large scale farmers. All farmer types recognised the positive effect of trees on air quality and indirectly on soil quality, through soil cover, plant residues and erosion control. Based on the community representation of all farmers, trees contribute most to air quality and water (both a relative weight of 0.35), production for consumption (0.20), wildlife (0.19) and shade (0.18). These represent 70% of all outdegree of trees.

3.3. Pesticides

Pesticides were mentioned by all 24 farmers. Agroecological and conventional family farmers perceived a stronger negative influence of pesticides on ecosystem properties and the delivery of ES than large scale farmers ($p = 0.019$ and $p = 0.035$, respectively; Table 2). Agroecological family farmers do not apply pesticides, whereas conventional family farmers apply pesticides themselves and large farmers often hire employees to do so. Large scale farmers recognised significantly more positive benefits of pesticides than agroecological family farmers ($p = 0.007$; Table 2). For the community of farmer types, the main identified negative impacts of pesticides were on health (a relative weight of −0.70), water (−0.67), air quality (−0.37), wildlife (−0.23) and soil quality (−0.19). These represent 89% of all negative outdegree of pesticides.

3.4. Peasant farming: labour and food sovereignty

Agroecological and conventional family farmers had a significantly smaller farm size, lower number of coffee plants and Tropical Livestock Units than large scale farmers (Table 1). The community dynamics of agroecological and conventional family farmers were different from large scale farmers. For instance, family farmers made use of their social network to acquire labour, mentioning labour exchange, family and the community as means to maintain agricultural production, whereas large scale farmers only referred to contracted labour. The production for consumption (food sovereignty) was significantly more central for agroecological family farmers than large scale farmers ($p = 0.023$; Table 2). Large scale farmers typically did not produce their own food, whereas all family farmers in this study had at least a small homegarden to produce food for home consumption.

3.5. Cultural ES

Agroecological family farmers identified significantly more cultural ES as compared to large scale farmers ($p = 0.014$; Table 2), but there was no significant difference between agroecological and conventional family farmers. The most important cultural ES for the community of farmers as a whole were autonomy (centrality score of 0.72), freedom (0.57), lifestyle (0.42), peacefulness (0.40) and aesthetics (0.38), representing 93% of the total cultural ES. For agroecological family farmers, autonomy (centrality score of 1.32) was by far the most central factor out of all cultural ES, for conventional family farmers it was the third highest cultural ES (0.54) and large farmers did not mention autonomy at all, indicating that this is not a concern for them.

3.6. Ecosystem components

For the community of farmers, the three most central ecosystem components were forest (centrality score of 1.97), trees (1.87) and wildlife (1.47), representing 79% of the centrality of all ecosystem components combined. Based on the centrality scores, no significant differences were found for the centrality of forest and wildlife among farmer types (Table 2).

3.7. Intermediate ES

Intermediate services were recognised as ordinary variables in 81% of all cases, indicating that farmers recognised both (i) how intermediate ES can be influenced (managed) by other factors in the system, and (ii) how they exert an influence on other factors (mostly direct ES) in the system. Soil quality has the highest centrality score (2.97) of all intermediate ES mentioned by all farmer types. Agroecological farmers recognised 20 different factors influencing soil quality, conventional farmers 9, and large farmers 11 factors. Based on the social FCM for all farmers, soil quality is most strongly influenced by manure (score of 8.6), pesticides (−4.5), limestone (3.5), plant residues (including tree's residues) (2.7) and water (2.7), representing 50% of all indegree of soil quality. Soil quality influences production (both for the market and self-consumption; score of 9.9) and water (5.0), representing 73% of all outdegree of soil quality. Only agroecological farmers recognised soil cover (5/10) and pollination (3/10) as an intermediate ES, with a centrality score of 0.64 and 0.27, respectively. Four out of ten agroecological farmers and one out of nine conventional farmer recognised natural pest control as an intermediate ES.

4. Discussion

Our study shows that (i) the perception of farmers on ES and their management is highly complex and interconnected, (ii) agroecological family, conventional family and large scale farmers have different perceptions of ES, and (iii) a more complex perception on ES is associated with more diversified and autonomous agroecosystems.

4.1. Farmer's perceptions on ES provision

The FCM showed that farmer's perceptions on ES and their management is complex, in particular for agroecological farmers. Asking farmers about their perceived benefits of nature without an a priori defined list of options brought forward a multiplicity of services that farmers value from their agroecosystems (Fig. 3, Appendix D). Farmers did not use specifically the concept of biodiversity as an ES, but would identify ecosystem components, such as on-farm trees, forest and wildlife, to provide intermediate services dependent on biodiversity, such as pest control, pollination, erosion control and seed dispersal. This is in line with most recent frameworks in which biodiversity and ecosystems have their own intrinsic value, but at the same time contribute to human well-being through the provision of ES (Díaz et al., 2015). These results also showed that farmers understand the complex and interconnected relationships between several ES and different aspects of the agroecosystem, such as management, ecosystem components and external inputs (Fig. 3). Consequently, studies that focus in one or two ES in isolation can only provide a limited understanding of the inherent complexity of the subject (Berthet et al., 2016). This is particularly relevant for assessments of realistic management scenarios because these scenarios encompass social and ecological multiplicities emerging from the interactions among local actors, agricultural management, natural conditions, and ecosystem properties and functions (Balvanera et al., 2014). In addition, farmers identified direct and intermediate services that benefit themselves (excludable), such as production for consumption, health and autonomy, but also services that serve society as a whole (non-excludable), such as water provision, production for the market, air quality and aesthetics (Fisher et al., 2009). Most cultural ES identified were intrinsic to being a farmer, such as autonomy, lifestyle and learnings from nature (Chan et al., 2012).

4.2. *Contrasting farmers' perceptions*

Agroecological family farmers, conventional family farmers and large scale farmers showed contrasting perceptions of ES. The differences in perceptions between family farmers and large scale farmers can be explained by the distinction between peasant farming and capitalist farming (Van der Ploeg, 2008). The peasant way of farming is characterised by a co-production with nature, building upon a resource base in which diversification strategies increase ES delivery, enhance agroecosystems resilience, reduce the reliance on external inputs, generate a variety of income streams from multiple crops, and increase food sovereignty (Van der Ploeg, 2010; Bennett et al., 2015). Indeed, both agroecological and conventional family farmers recognised more direct ES, and produced more food for home consumption than large scale farmers, for instance in home gardens. Family farmers also recognised a stronger negative impact of pesticides (Table 2) than large scale farmers, since they apply pesticides in the field themselves (conventional family farmers) or used to do so in the past (agroecological family farmers). In the case of conventional family farmers (including sharecroppers) this reflects a paradoxical situation in which the negative consequences of pesticides are recognised, but farmers continue using chemical pesticides because they do not see an alternative or are pressured by their landlords, who do not tend to recognise the negative impacts of pesticides on health. Large scale farmers with a more entrepreneurial way of farming had a stronger focus on commodity production and a less complex perception of the interactions between agroecosystem components than family farmers. This can in part be explained by low diversity of the cropping systems of large scale farmers, which were often monocultures of a limited set of crops. While our study confirms earlier findings about the differences between family and capitalist farming in terms of farm size, market-orientation, resource endowment and reliance on contracted labour (Vanhaute and Cottyn, 2017), we also show that family and capitalist farmers differ in their perception of the complexity of agroecosystems and the associated ES. Depending on the land tenure arrangement, peasants tend to conserve nature as a long-term investment in the ecological capital of the farm. The adoption of agroecological practices allow farmers to produce agricultural goods and services, while safeguarding the ecological capital for future generations (Van der Ploeg, 2014). In contrast, large-scale farmers tended to see land, labour and nature as commodities that can be replaced or sold in case of obsolescence. As a consequence, large-scale farmers tended to focus on maximizing cash crop production at the short term, neglecting possible negative impacts on production potential on the longer term, and the provision of other ES, such as soil quality, health, air quality and water provision. In future studies, it would also be interesting to focus on the perception of farmers working as employees at large scale farms. This could give new insights on the connection of this specific group of farmers with land and nature, as well as the power relationship between landlords and employees.

Conventional family farmers in Zona da Mata still embody many traditional aspects of peasant farmers, such as home gardens for food self-sufficiency, a strong reliance on the community for labour and a close connection to nature. Yet, their farming practices are moving towards an entrepreneurial way of farming with high external inputs and a loss of autonomy. The remaining peasant identity of conventional family farmers could be an important basis for enhancing the transition towards agroecological farming practices. The persistence of the peasant way of farming in Zona da Mata can be explained by two factors. First, the hilly landscape hampered agricultural mechanization and the spread of the associated Green Revolution practices (Freitas et al., 2004; Souza et al., 2012). This may have limited the capitalist way of farming in the region. Second, the peasant identity in the Zona da Mata region has been strengthened by the action of Grassroots Ecclesial Communities (Comunidades Eclesiais de Base, CEBs). The CEBs, which originated during the end of the dictatorship in Brazil in the 1980s, made agroecological concepts meaningful to farmers within a religious and political context by the organisation of reflection groups (Botelho et al., 2015). The reflection groups have been active in the municipalities included in our study and may have therefore influenced the perception of conventional and agroecological family farmers by encouraging farmers to claim the right to land and autonomy, strengthen community building and self-organisation, respect culture, nature and human rights, and embrace Christian religion (Cardoso and Mendes, 2015). During the construction of the FCMs, many farmers mentioned God as the most important overarching factor, which was connected to all identified factors. Due to practical constraints it was not possible to include the perceived interconnectedness of God with the other factors in the FCM.

The interaction between the limited uptake of Green Revolution practices and the activity of grassroots organisations has resulted in a relative widespread adoption of agroecological practices among family farmers in the Zona de Mata, but the uptake is often lower in regions of Brazil that have been more conducive for the Green Revolution approach.

4.3. *From perception to diversification*

The transition towards agroecology in the Zona da Mata allowed the co-creation of knowledge based on peasant experience and creativity, and contributions from researchers and extension services (Cardoso et al., 2001; Souza et al., 2012). The co-creation process was led by farmers organisations and was supported by a participatory approach similar to the peasant-to-peasant methodology (Rosset et al., 2011) in which scientific and empirical knowledge was combined and extended (Zanelli et al., 2016). The generated knowledge is based on peasant culture as well as the understanding of ecological processes, species interactions and relationships between ecosystem structure and function. This knowledge base was reflected in the FCM by the fact that agroecological family farmers recognised a higher number of intermediate services and benefits from trees, a higher number of connections between agroecosystem components, and relied less on external inputs in comparison to conventional family and large scale farmers (Tables 1 and 2). The positive correlation between farmer's perception of the complexity of the agroecosystem in the FCM and the number of crops grown and products sold, indicates that the generation of agroecological knowledge can contribute to the development of diversified agroecosystems and the associated ES (Duru et al., 2015). These results also reflect the higher level of food sovereignty among agroecological family farmers, who gained control over land and adopted farming practices that allow to break free from the dominant agri-food system. For instance, agroecological family farmers conserve and propagate native crop varieties, cultivate and use medicinal plants, use ecological water treatment, produce a variety of crops for self-consumption and have established agroforestry systems in their farms. To foster the process from perception to diversification, involvement of social organisations is indispensable, such as farmers unions and NGO's, to empower farmers, to develop actionable knowledge to support agroecological innovation (Geertsema et al., 2016), and ultimately contributing to diversified agreocosystems and food sovereignty.

For developing effective policies to promote biodiversity-based agriculture and support a peasant way of farming, the creation of a bottom-up process to stimulate farmers' participation and representation may be beneficial (Vuillot et al., 2016; Bernués et al., 2016). For instance, the National Program of School Feeding in Brazil (PNAE), promoted the dialogue between family farmers and the government to enable the commercialization of a diversity of agricultural products to schools (Mossmann et al., 2017). Family farmers are often limited to sell only few types of products due to market constraints, as was the case of conventional family farmers in our study, and are therefore discouraged to produce a diversity of crops and promote agrobiodiversity (Wittman et al., 2017). In addition, reform of environmental laws may be needed to strengthen the agrobiodiversity in agroecosystems. For instance, family farmers express the desire to manage native on-farm trees, but management of native trees is restricted by a law that aims to conserve these trees. Although farmers recognise the benefits and functions of trees on the farm (Table 2), farmers are discouraged to introduce native trees because they are afraid to be punished in case the trees need to be managed or cut (FAO, 2013). Ultimately, policies need to be sensitive to farmers needs and perceptions in order to be socially accepted and implemented successfully. For instance, our study shows that for the interviewed farmers, water was the most important ES. This highlights the need for programs and projects aiming at water conservation through practices already familiar to farmers (based on the FCMs), such as fencing water springs, planting on-farm trees, enabling natural regeneration of forest patches, improving soil quality and reducing the use of pesticides.

The variation in the farmers' perceptions on ES that we found in our study triggers the question to what extent current extension programs match with the way how farmers understand their agroecosystem. Extension services often focus on increasing the productivity of cash crops and advise on operational decisions (Dogliotti et al., 2014). Yet, family farmers have empirical local knowledge and often value multiple benefits from their agroecosystems beyond food production for the market, indicating that there is a need for more integrative and holistic extension programs. To inform such programs, it would be worthwhile to explore the trajectories of different farmer types to further investigate the process of knowledge construction in connection to value systems and culture, including spirituality. Finally, from an ecological perspective, it is crucial to understand the interactions between ES, ecosystem properties, functional diversity and management, aiming to optimize the delivery of multiple ES in agroecosystems.

4.4. Reflection on methodology

The FCM proofed to be an effective participatory tool that allowed to capture farmers perception and knowledge on the interactions between social and ecological components for the provision of ES in agroecosystems. The number of interviews conducted and the average number of factors and connections obtained with the FCM in this study are in line with previous studies in social environmental research (Özesmi and Özesmi, 2004). However, most variables did not follow a normal distribution, which resulted in a loss of statistical power associated with the use of non-parametric tests (Field, 2013). Despite the limited statistical power, we identified significant differences among different farmer types. Furthermore, we constructed social FCMs by aggregating individual FCMs. This is a commonly used method that can be helpful to reveal and contrast patterns found in different actor groups (Jetter and Kok, 2014). Given that the social FCMs are created by merging the factors and connections raised by all farmers in the group, this can lead to overly complex representation of the perception of an individual farmer. Therefore, the interpretation of the social FCM needs to take into account potential artefacts associated with the merging of individual farmer responses into group responses. Nevertheless, in our study the group responses provided a fair representation of the responses from individual farmers, which was confirmed during workshops to present and validate the results to the farmers in the three municipalities, and therefore we are confident that the analysis at the group level provides credible and relevant insights.

5. Conclusions

Our study highlights the diversity of farmer's perceptions on ES and their management. Understanding the differences and similarities between the diverse visions on quality of life and the factors involved in the provision of ES is an important step to engage with different stakeholders and associated knowledge systems within an ES and biodiversity framework. Initiatives that aim to strengthen on-farm ES should be sensitive for farmer's perceptions and may need to consider using specific strategies for different farmer types. Large scale farmers with a more capitalist way of farming may become interested in diversified cropping systems if these are more profitable and more stable than monocrops, and when crop management can be mechanized. For family farmers, the agroecology movement has played a pivotal role in creating awareness about ES and develop and disseminate actionable knowledge for the management of diversified agroecosystems. Yet, promoting family farmers' access to knowledge, credit and extension services, and at the same time valuing and (re)signifying the peasant identity and culture remains crucial. The involvement of social organisations may help to engage, empower and give voice to family farmers. Support by policies and institutions is also needed to promote farm diversification strategies and provide favourable socio-economic conditions for farmers to move towards agroecological, autonomous and diversified agriculture.

6. Conflict of interest

The authors have no conflict of interest.

Acknowledgement

We acknowledge support through the Interdisciplinary Research and Education Fund (INREF) of Wageningen University through its programme FOREFRONT. We thank Pablo Tittonell for helpful discussion to develop the initial idea for this paper. Foremost, we would like to thank the farmers, farmer organisations', CTA-ZM and the agroecology movement in Zona da Mata for making this research possible. This work would not have happened without the great involvement of all members of the FOREFRONT project, forming together a truly interdisciplinary research team.

Appendices

Appendix A

Fig. A1

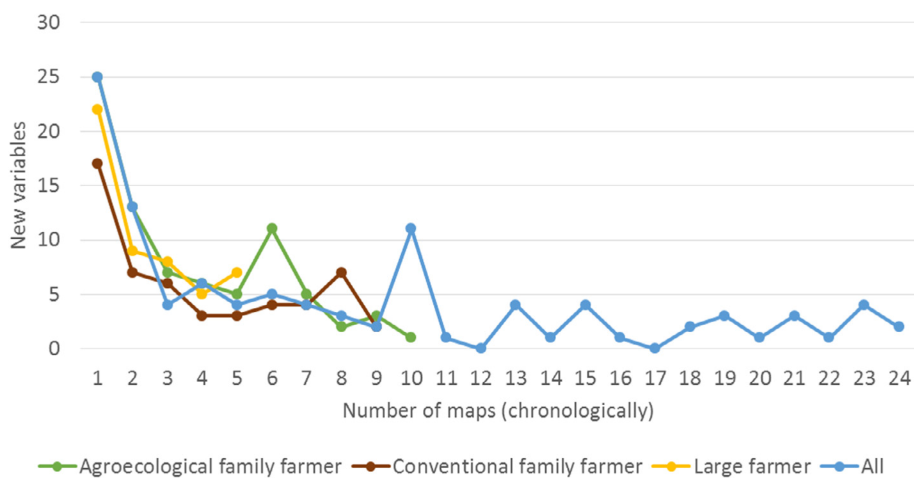
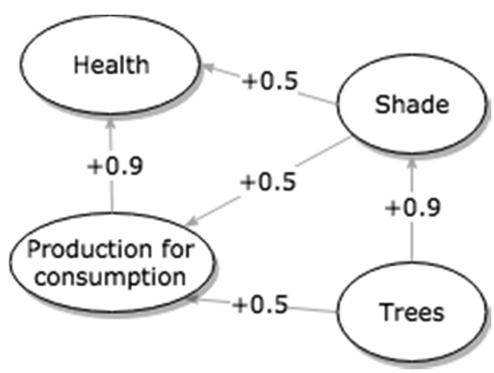


Fig. A1. Accumulation curves of the number of new variables per interview to assess the saturation in responses per farmer type.

Appendix B

Appendix B

Appendix B
Example of coding the results of the fuzzy cognitive map to the adjacency matrix. The selected section of the fuzzy cognitive map is taken from Fig. 2.



	Health	Prod. consump.	Shade	Trees
Health	0	0	0	0
Prod. for consumption	0.9	0	0	0
Shade	0.5	0.5	0	0
Trees	0	0.5	0.9	0

Appendix C

Fig. C1, Table C2.

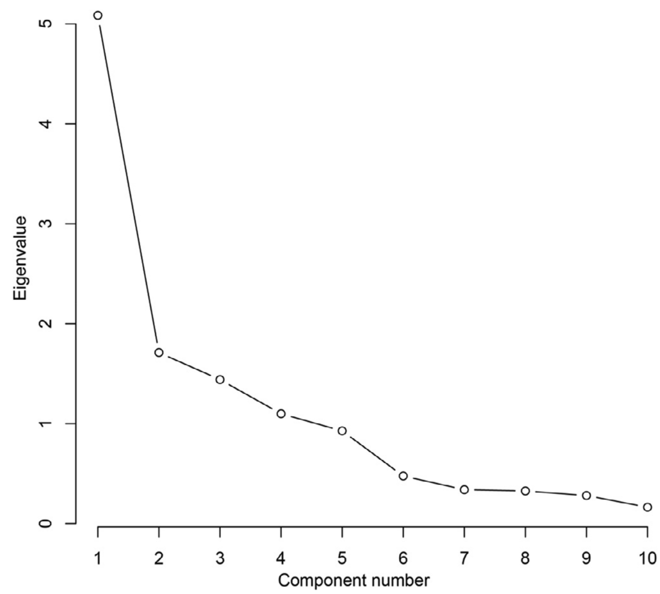


Fig. C1. Screen plot for selecting the number of components in the Principal Component Analysis (Fig. 4).

Table C2
Correlation coefficients of selected variables with PCA axis 1 and 2 as shown in Principal Component Analysis (Fig. 4).

	PCA axes	
	1	2
Factors	0.706	0.069
Crop diversity	0.665	0.427
Products sold	0.733	0.051
Trees benefits	0.758	0.272
Production consumption centrality	0.100	0.791
Direct ES	0.277	0.815
Intermediate ES	0.738	0.011
External input	−0.621	−0.272
Cultural ES	0.333	0.495
Pesticides negative outdegree	0.090	0.510
Connections	0.704	0.494
Land size	−0.054	−0.855

Appendix D

Appendix D.

Appendix D
Correlation coefficients of selected variables with PCA axis 1 and 2 as shown in Principal Component Analysis (Fig. 4).

Agroecological family farmers		Conventional family farmers		Large scale farmers	
Concepts	**Centrality**	**Concepts**	**Centrality**	**Concepts**	**Centrality**
water	6.38	water	6.33	production market	5.64
production consumption	5.14	production market	4.67	water	4.90
production market	3.94	production consumption	4.56	soil quality	2.64
health	3.40	soil quality	2.93	forest	1.86
soil quality	3.28	pesticides	2.78	production consumption	1.78
trees	3.11	health	2.76	health	1.72
pesticides	2.39	air quality	1.94	pesticides	1.56
forest	2.30	forest	1.77	erosion control	1.26
wildlife	2.01	manure	1.39	chemical fertilizer	1.06
soil cover	1.54	chemical fertilizer	1.27	manure	0.98
air quality	1.53	wildlife	1.22	animal husbandry	0.94
autonomy	1.32	trees	1.18	climate	0.90
medicinal plants	1.31	weeding	1.09	wildlife	0.84
diversification	1.05	trimming	0.87	freedom	0.72
manure	0.95	protecting springs	0.86	air quality	0.72
shade	0.88	plant residues	0.74	protecting springs	0.72
pest control	0.85	fire	0.69	weeding	0.72
freedom	0.77	peacefulness	0.66	water boxes	0.68
chemical fertilizer	0.71	lifestyle	0.58	trees	0.64
erosion control	0.66	autonomy	0.54	fire	0.54
pollinisation	0.64	coffee husks	0.43	coffee husks	0.52
family labour	0.62	landownership	0.38	machinary	0.52
seeds and seedlings	0.62	eucalyptus	0.37	roads	0.50
esthetics	0.59	calcium	0.33	cooldown soil	0.46
trimming	0.58	community	0.28	diversification	0.46
lifestyle	0.48	freedom	0.26	trimming	0.46
eucalyptus	0.46	labour exchange	0.26	homeopathy	0.38
protecting springs	0.45	family labour	0.26	generating work	0.36
climate change	0.42	pest control	0.23	silage mais	0.36
peacefulness	0.38	erosion control	0.21	trash	0.36
fire	0.36	trash	0.21	eucalyptus	0.32
sanitation	0.36	rain	0.20	feed	0.32
weeding	0.36	ox cart	0.20	foliar fertilizer	0.32
knowledge	0.32	water boxes	0.20	esthetics	0.32
biodigestor	0.28	labour contracted	0.19	animal medication	0.28
intercropping	0.27	esthetics	0.18	contour lines	0.28
climate	0.27	seed dispersal	0.18	labour contracted	0.28
homeopathy	0.27	foliar fertilizer	0.16	water resevoirs	0.24
plant residues	0.27	wood	0.13	plowing along	0.24

(continued on next page)

Appendix D (*continued*)

				contour lines	
calcium	0.26	seeds store	0.13	calcium	0.18
microorganisms	0.25	homeopathy	0.10	climate change	0.18
cultural valorisation	0.25	wastage	0.10	deplete swamp	0.18
seed exchange	0.25	clearing the soil	0.08	plant residues	0.18
care for plants	0.23	deplete swamp	0.08	shade	0.18
generating work	0.23	product exchange	0.08	soil analysis	0.18
debt	0.18	silence	0.08	animal comfort	0.14
teachings from nature	0.18	swales	0.08	bureaucracy	0.10
waste water treatment	0.18	terraces	0.08	clearing the soil	0.10
organic matter	0.18	working independently	0.08	slurry	0.10
rain	0.18	health clinic	0.06	subcontractors	0.10
seed dispersal	0.18	machinary	0.06	silage grasses	0.06
water boxes	0.16	soil analysis	0.06		
trash	0.15	pasture	0.03		
nutrients	0.15				
community	0.14				
connection with nature	0.14				
contour lines	0.14				
labour exchange	0.14				
transgenics	0.14				
Handcrafts	0.12				
coffee husks	0.12				
adapted seeds	0.09				
agribusiness	0.09				
deplete swamp	0.09				
landownership	0.09				
over grazing	0.09				
rotation and fallow	0.09				
labour contracted	0.09				
dependence on the market	0.07				
foliar fertilizer	0.07				
path design	0.07				
recycling	0.07				
spontaneous plants	0.07				
typography of pasture	0.07				
darkness	0.05				
nitrogen fixation	0.05				
planting in tires	0.05				
swales	0.05				

Legend
direct service
intermediate service
ecological property
management
external input
social-economic

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