


Article

Understanding Farm Diversity to Promote Agroecological Transitions

Heitor Mancini Teixeira ^{1,2,3,*} , Leonardo van den Berg ^{4,5}, Irene Maria Cardoso ²,
Ardjan J. Vermue ¹, Felix J. J. A. Bianchi ¹, Marielos Peña-Claros ³ and Pablo Tittone ^{6,7}

¹ Farming Systems Ecology Group, Wageningen University & Research, P.O. Box 430, 6700 AK Wageningen, The Netherlands; ardjan.vermue@gmail.com (A.J.V.); felix.bianchi@wur.nl (F.J.J.A.B.)

² Department of Soil and Plant Nutrition, Federal University of Viçosa, campus UFV, 36570-900 Viçosa, Brazil; irene@ufv.br

³ Forest Ecology and Forest Management Group, Wageningen University & Research, P.O. Box 47, 6700 AA Wageningen, The Netherlands; marielos.penaclaros@wur.nl

⁴ Forest and Nature Conservation Policy, Wageningen University & Research, P.O. Box 47, 6700 AA Wageningen, The Netherlands; leonardo.vandenberg@wur.nl

⁵ Department of Rural Economics, Federal University of Viçosa, campus UFV, 36570-900 Viçosa, Brazil

⁶ Agroecology, Environment and Systems Group, Instituto de Investigaciones Forestales y Agropecuarias de Bariloche (IFAB), INTA-CONICET, Modesta Victoria 4450-CC 277, 8400 San Carlos de Bariloche, Río Negro, Argentina; tittone.pablo@inta.gob.ar

⁷ Groningen Institute of Evolutionary Life Sciences, Groningen University, P.O. Box 11103, 9700 CC Groningen, The Netherlands

* Correspondence: heitor.manciniteixeira@wur.nl; Tel.: +55-31-997-138-377

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Abstract: Agroecology is increasingly promoted by scientists, non-governmental organisations (NGO's), international organisations and peasant movements as an approach to foster the transition to sustainable and equitable food systems. The challenges to agroecological transitions are not the same for all farmers, as they can face different social and bio-physical conditions. We developed a farm typology combining participatory and quantitative methodologies to assess and categorise farm diversity and its implications for developing strategies to promote agroecological transitions. The participatory typology was developed during workshops to acquire insights on local farmers' perceptions and knowledge, and to generate hypotheses on family farm diversity. The participatory-based hypotheses were tested in the quantitative farm characterisation, which provided information on household characteristics, production strategies, land use, participation in public policies and extension services. Farms were located in Zona da Mata, Minas Gerais, Brazil, which harbour a wide diversity of farmers and where different actors have been engaged in agroecological transitions for the past 30 years. Our main findings were: (i) In the face of agroecological transitions, farmers differ in their management strategies, practices and principles; (ii) farmers identified as agroecological typically had stronger engagements in a network composed of farmers' organisations, universities and NGO's; (iii) agroecological farms showed great potential to provide a wide range of ecosystem services as they featured a higher crop diversity and a higher number of crops for self-consumption; (iv) to promote agroecology, it is crucial to recognise peasant knowledge, to change the dominant discourse on agriculture through social movement dynamics, and to generate support from public policies and funds; and (v) participatory and quantitative methodologies can be combined for more precise and relevant assessments of agroecological transitions.

Keywords: peasant; agroecological practice; participatory farm typology; statistical farm typology; participatory action research

1. Introduction

Agroecology as an approach to foster the transition to food systems that conserve resources and improve human well-being [1–3], has been increasingly promoted by scientists [4,5], Non-Governmental Organisation (NGOs) [6], international organisations [7], and peasant movements [8]. Agroecology advocates for small-scale, autonomous, resilient and efficient farming systems, that also value human rights (including women, youth and indigenous people), local cultures, social participation and food traditions [7]. At the farm level, agroecology favours practices based on multi-functionality and biodiversity to reduce the dependence on external agrochemical inputs and to enhance ecological processes [9,10]. Agroecological practices are knowledge intensive and tailored to local ecological conditions and cultural knowledge [11,12]. Agroecological practices can be technically oriented, such as composting or biocontrol and/or more socially oriented and promote, for instance, gender equality or local culture. Policies can advance agroecology by supporting agroecological research and the development of agroecological practices, and by ensuring that farmers have access to and security over land, and access to markets that valorise agroecological farmers and their produce [13–15].

The agroecological transition is defined as the gradual change that farmers undergo to adapt and move from more conventional towards agroecological farming principles, encompassing technological, societal, institutional and organisational changes in the food system [16,17]. Agroecological transitions are often developed within a group of farmers at the community, municipality, regional and/or even international levels [18], and may influence the ways how farmers organise themselves, value their traditional culture, and relate to each other and other stakeholders. Although the transition to agroecology follows general principles, each particular farm has a unique way to adopt and adapt practices and management strategies. Therefore, the challenges towards agroecological transitions are not the same for all farmers as farmers differ in objectives and values [19], and are embedded in different social and ecological contexts [20,21].

To assess the implications of farm diversity for promoting agroecological transitions, two main challenges need to be addressed. The first challenge refers to a conceptual and empirical understanding of how to assess the diversity of farmers within transition processes. Earlier studies have sought to understand the diversity of farmers through the notion of “farming styles” or “farm typologies”, which distinguish different groups of farmers on the basis of the strategies that they pursue, as well as farm structural variables [22–25]. Farmers are embedded in different social networks that expose them to particular discourses, but that also grant farmers access to particular resources, information on farming practices, and public policies [21,26]. It is not clear how practices, discourses and policies associated with different farming types favour or hamper agroecological transitions and what types of interventions could best advance the transition for different farm types. The second challenge refers to an adequate methodological approach to understanding the relation between farm typologies and transition processes. Several researchers have argued that classifying and characterizing different types of farms in a way that is both precise and relevant requires the use of both quantitative and qualitative indicators and methods [27,28]. Others added that for a precise and relevant characterisation, researchers must engage with farmers’ own knowledge, values and aspirations [29]. To derive a meaningful farm typology it is important to use indicators that reflect the farmers’ purposeful actions, which requires the thorough knowledge of farmers’ intent and perceptions. Participatory methodologies can be used to convey local knowledge and to stimulate farmers involvement in the research, increasing the effectiveness and applicability of the results [30,31]. It is not clear, however, how participatory methodologies, and what combination of quantitative and qualitative methods, can best be used to understand how farm diversity relates to practices, discourses and policies.

In this study we assess how agroecological practices and principles are associated with different farm types within a process of agroecological transition. We assess variations between farm types and describe implications for promoting transitions. We also discuss how and why quantitative and participatory methodologies can be combined for more precise and relevant assessments to

understand and promote agroecological transitions. The research questions are: (i) How do farm types differ in agricultural practices and management? (ii) How conducive are different farm types for fostering agroecological transitions? (iii) How can different research methodologies contribute to the understanding of farm diversity to promote agroecological transitions? For this purpose, we developed and evaluated a farm typology combining participatory and quantitative methodologies, analysing data collected in the Zona da Mata, Minas Gerais, Brazil. The Zona da Mata is a suitable area to conduct this research because although different actors were engaged in agroecological transitions for the past 30 years [12], the region still harbours a wide diversity of farming systems. The agroecological transition is driven by farmers and their organisations in cooperation and partnership with the University of Viçosa (UFV), the socio-environmental NGO Centro de Tecnologias Alternativas da Zona da Mata (CTA-ZM), and other organisations and social movements present in Zona da Mata [12].

2. Methods

2.1. Study Region

The Zona da Mata region is located in the south-eastern part of the state of Minas Gerais, Brazil. It is part of the Atlantic rainforest biome, considered the 5th biodiversity hotspot in the world, due to its unique and threatened fauna and flora [32]. The area is mountainous, leading to a diverse set of bio-physical conditions, limiting mechanisation and favouring small scale farming. The average temperature in the region is 19 °C, average precipitation is 1300 mm, with 3–4 dry months per year. Altitude ranges from 200 to 1800 m [33]. The main soil type is classified as Oxisol, which is highly weathered, deep, well-drained and acidic.

The region was populated by native indigenous communities, who were colonised and nearly extinguished with the arrival of the Portuguese crown in the eighteenth century. After the colonisation, at the beginning of the nineteenth century, the land was divided among aristocratic landlords from other parts of the country. The farms were established based on the slave labour of black Africans, and coffee cultivation became the main cash crop in the region. When slavery was abolished in 1888, lack of labour became a major problem on the farms [34]. Another problem was the decline of soil fertility, which resulted from many years of coffee production under poor management conditions with low adoption of conservationist practices and low nutrient input. At the beginning of the twentieth century, coffee production started to decline. Degraded coffee plantations were replaced by pastures, leading to great areas of pastures dominated by grasses, such as *Brachiaria* spp. and *Melinis minutiflora*. Since there were no more slaves, landlords were forced to contract labour. This was done mainly in two ways: Hiring rural workers per day of work or signing a contract with sharecroppers. Sharecroppers were allowed to live and work on a portion of land, and in compensation the agricultural production had to be divided with the landlord. The workers used to live in poor conditions, were subjected to the orders of the landlords and had no autonomy. Within decades, diverse social dynamics in the region led to the division of land, mainly through heritage and land acquisition by rural workers [35]. Nowadays, family farms represent around 82% of the total number of farms in the region while more than a half of the land is owned by medium and large-scale farmers [36], and sharecropping is still common. To be considered a family farm according to the Brazilian law, the following criteria must be met: (i) Farm size is less than 96 ha of land; (ii) farm labour and management is predominantly provided by family members; and (iii) the main family income comes from rural activities [37]. The mountainous relief and current predominance of family farmers led to a diverse landscape in Zona da Mata, which can be understood as a dynamic mosaic of land uses, dominated by pastures, coffee fields and secondary forest patches.

The study is conducted in three municipalities of Zona da Mata: Divino, Araponga and Espera Feliz. These municipalities have a strong tradition with coffee production and are part of a long-term participatory process of agroecological transition, which started in the 1970s [12]. The municipalities

also connect two important nature conservation areas: The national park “Caparaó” and the state park “Serra do Brigadeiro” (Figure 1).

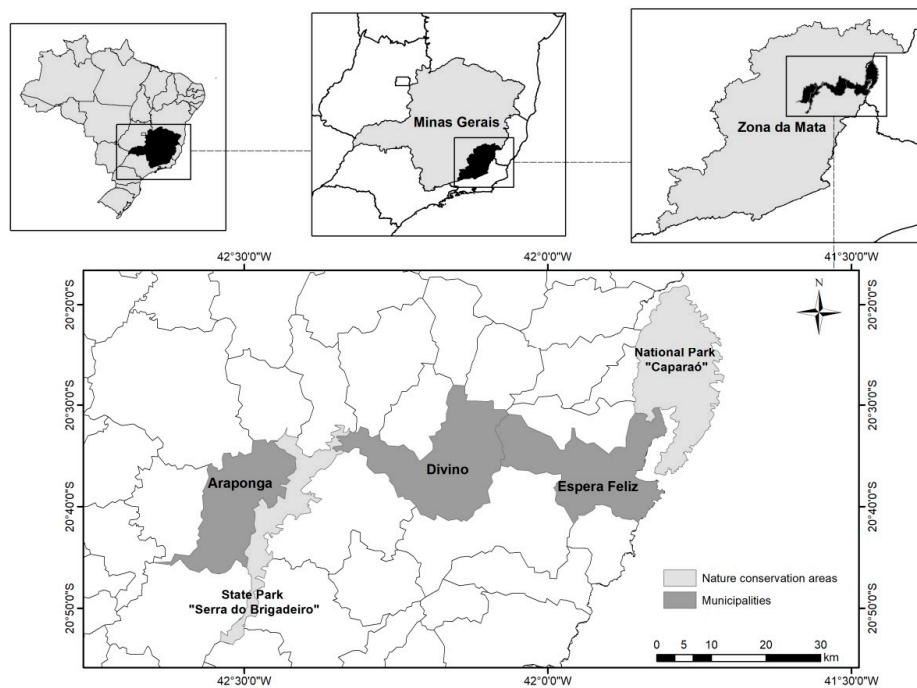


Figure 1. Map of studied municipalities in Zona da Mata, Minas Gerais, Brazil. The two protected areas of the region are also shown.

2.2. Farm Typology Construction

A farm typology was constructed using two complementary methods: A participatory typology through workshops with farmers in the three municipalities, and a quantitative analysis based on the characterisation of farming systems. The participatory typology was used to gain insights on farmers’ perceptions and knowledge, and to generate hypotheses on family farm diversity in Zona da Mata region. The participatory-based hypotheses were subsequently tested in the quantitative farm characterisation, which provided information on household characteristics, production strategies, land use, participation in public policies and extension services.

2.2.1. Participatory Typology

The participatory typology was informed by three workshops, one in each municipality (Figure 2). These workshops were embedded in a long-term action research process in the Zona da Mata region [38]. The workshops involved young to old local farmers and representatives of local organisations. The number of farmers participating in each of the three workshops was 18, 20 and 34, respectively, for a total of 72 participants. During the workshops, farmers were divided into two or three groups of 6–15 persons. The process in each group was facilitated by one or two researchers. During the workshops, farmers and scientists actively participated in a process of co-creating knowledge, whereby scientists withheld from providing their opinion, but facilitated and systematised the process based on farmers’ perceptions and knowledge.

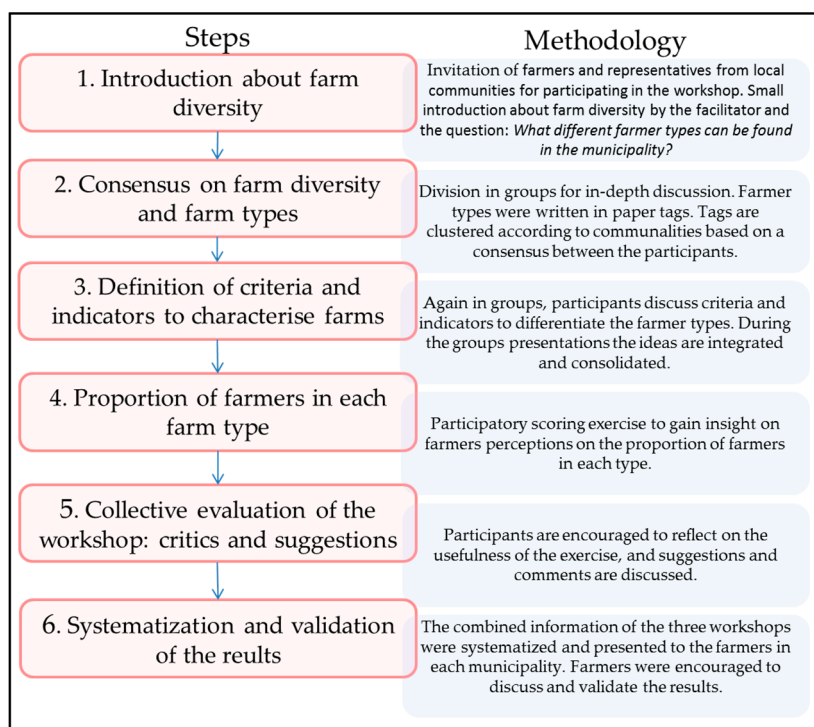


Figure 2. Steps of the participatory methodology developed in our study, which was used to understand farmers' perspectives on farm diversity in the Zona da Mata.

The indicators and criteria for characterising farm diversity defined during the participatory workshops in each municipality were recorded, compiled and systematised in a matrix to characterise a regional typology. The importance of each indicator was not weighed, although some indicators can play a more important role than others to characterise the different farmer types. During the systematisation, we only selected information that was common to the three municipalities. After the systematisation, the results were presented to farmers in each municipality to validate the results obtained for the region. Finally, based on the results of the participatory workshops, we created hypotheses on family farm diversity.

The workshops for developing the farm typology were embedded in an action research process, in which researchers participated in activities together with farmers, such as visiting and working in their fields, participating in meetings, workshops and social events. Furthermore, we shared the knowledge generated by this study in formal and informal ways, fostering reflections and discussions and promoting the exchange of knowledge.

2.2.2. Farm Characterisation and Quantitative Typology

The quantitative typology was based on a data set of 115 family farming systems selected by the family farmers' unions, which are active in each of the three municipalities, to capture the diversity of family farming systems in the region (Figure 1). The unions approached random families of their network, indiscriminately of farmers did or did not participate in the participatory typology workshops. As the unions are responsible for public services, such as rural retirement, they have contact with a great proportion of family farmers in the municipalities. Only family farmers were selected for the quantitative analysis, because they represent the largest proportion of farmers (82%) in Zona da Mata [36] and are considered prime targets of agroecological transitions, since they own land, and, therefore, have more autonomy to manage the land and are more interested to conserve the ecological capital based on local and traditional knowledge [39,40]. Data collection was conducted in partnership with the local NGO CTA-ZM and researchers in 2015 and 2016 as part of a publicly funded assessment to characterise agroecosystems based on functional and structural farm variables. The information was

obtained by Participatory Rural Appraisal (PRA) techniques, including semi-structured interviews, transect walks on the farm, participatory mapping of the farm and mapping of the gender division of labour [41,42].

Based on the outcomes of the participatory workshops, data availability and consistency, we selected seven meaningful quantitative variables to categorise farm households in terms of farm structural, management and social aspects (Supplementary Materials Table S1). The variables were: (i) *n.policies*—number of public policies in which households participated; (ii) *n.CTA*—number of extension projects from the local NGO (CTA-ZM) in which households were engaged; (iii) *n.prod*—number of crop products produced on the farm; (iv) *n.pract*—number of agroecological practices and principles adopted on the farm; (v) *age*—age of the household head (in years); (vi) *farm.area*—farm area (in hectares); and (vii) *n.consumed*—number of food items produced on the farm consumed by the family. The variables *n.CTA* and *n.policies* are used, respectively, as proxies for the extent of involvement in social networks and participation in public policies. To assess the number of adopted agroecological practices (*n.pract*), we used a checklist of practices that were previously defined by technicians of the CTA-ZM in collaboration with family farmers of the region (Supplementary Materials, Table S2).

Multivariate Analysis and Farm Classification

Principal component analysis (PCA) was used to generate non-correlated principal components (PC's), and cluster analysis for grouping farms into clusters based on their position on the PCA axes [22,28,43]. We did not include the variable “number of food items produced on the farm consumed by the family” in the multivariate analysis, because it was strongly correlated with the variable “number of crop products” obtained on the farm (correlation coefficient >0.9; Supplementary Materials Figure S1). The first two axes of the principal component were considered for the subsequent cluster analysis. These two axes were selected according to the Kaiser criterion, which indicates the selection of any axis with eigenvalues greater than 1. For the cluster analysis, we used a hierarchical, agglomerative clustering algorithm using Ward's method to define the number of groups (*k*). The final set of clusters was based on the inherent structure (i.e., the mean value of each variable for each cluster) aiming at intra-cluster homogeneity and inter-cluster heterogeneity (Supplementary Materials Figure S2). In addition, after classifying the farms according to the cluster analysis, we developed a binary recursive partitioning tree classification model to visualise decision rules for predicting the classification of farms on the different farm types according to the six selected variables.

Characterisation of Different Farm Types

We tested whether farm types defined in the cluster analysis explained variation in the seven quantitative variables listed earlier. We used one-way ANOVA and Tukey post-doc tests for variables with normal distributions and homogeneous variances, and the non-parametric Kruskal-Wallis test and post-doc Dunn test when this was not the case. For proportional data we used Pearson's Chi-squared and Fischer tests. *p*-values are mentioned throughout the manuscript.

Agroecological Practices and Principles

We used neural network analysis to assess the agroecological practices and/or principles associated with each farm type [43] and that can affect the provision of ecosystem services [44]. The neural network was constructed based on a presence/absence table representing the adoption (or not) of 25 types of agroecological practices and principles on each farm (Supplementary Materials Table S2). These 25 practices were taken from the above mentioned checklist. The association of each of the 25 practices with the farm types were visualised using the software Gephi 0.9.2 [45]. The closer the distance between each practice to the specific farm type in the neural network, the more affinity the farm type has to such practice. All the statistical analyses were conducted in R (version 3.3.3).

3. Results

3.1. Participatory Typology

Six main farmer types were identified during the participatory workshops: Agroecological family farmers, traditional family farmers, conventional family farmers, part-time farmers, large scale farmers and landless farmers (Table 1 and Supplementary Materials Table S3). Based on the participatory scoring exercise, 54.1% of the farmers are considered family farmers that own land, 22.6% landless farmers, 13.3% large-scale farmers and 10% part-time farmers. Among the family farmers, 19.6% of the farmers are conventional family farmers, 18.3% are traditional family farmers and 16.2% are agroecological family farmers.

Agroecological family farmers have a high level of autonomy and a strong connection with nature. They have diversified production systems, make little use of external inputs, do not use pesticides, use landrace seeds and adopt innovative farming practices. Agroecological farmers are part of a social network that includes farmers' organisations, religion-based organisations, universities and NGO's. *Traditional family farmers* still hold peasant characteristics, such as the use of landrace seeds, cultivation of diversified home gardens for self-consumption and rely on family labour, which contributes to their autonomy and food sovereignty. They often make use of traditional practices considered, nowadays, harmful to the environment, such as fire and intensive weeding. Traditional farmers make little or moderate use of pesticides and chemical fertilisers, especially in coffee systems. *Conventional family farmers* have a strong focus on coffee production. Conventional farms are less diversified than agroecological or traditional family farms, and strongly rely on pesticides and chemical fertilisers. A large proportion of food for household consumption is often purchased. Conventional farmers were early adopters of 'Green Revolution' technologies and are often part of a network consisting of suppliers of chemical inputs and government extension services. *Part-time farmers* have off-farm jobs besides their farming activities. Their main farming activity is coffee production for the market, which may be combined with the production of other crops. Their parallel jobs are often related to farming activities, such as commercialisation of agricultural inputs and cash crops. Part-time farmers can have a strong opinion on the benefits of agrochemical inputs and were found to promote the Green Revolution discourse amongst family farmers. *Large-scale farmers* have large farm areas, high coffee productivity with the high use of external inputs and hired labour. Both large-scale and part-time farmers adopt practices that can be considered conventional, such as intensive use of pesticides, fertilisers and monocultures. However, they may adopt some agroecological practices, as long as they are economically feasible and profitable, such as the use of manure, mowing instead of intensive uproot weeding and introduction of one or two tree species in the coffee fields and pastures. Large-scale and part-time farmers often set themselves as examples of the wealth that can be attained when following the principles of intensive agriculture. Together, they can also control parts of the coffee supply chain and hold high positions in the public administration of the municipality. *Landless farmers* do not own land and work as land labourers on other farms. They are hired by landlords and therefore do not have any autonomy with regards to land management decisions.

The participatory typology and associated discussion yielded four hypotheses on family farm diversity, which were further explored in the quantitative analysis: (i) Agroecological family farms have higher crop diversification, higher food-security, higher adoption of organic farming practices and higher social participation than conventional and traditional family farms; (ii) The household head of traditional family farms is older than in conventional and agroecological family farms; (iii) Agroecological, traditional and conventional family farms do not differ in terms of farm size; and (iv) Traditional family farms have higher crop diversification and higher food-security than conventional family farms, but lower than agroecological family farms. These hypotheses were developed to be further tested and explored in the quantitative typology.

Table 1. Overview of the consolidated criteria and indicators for characterizing the six different farm types based on the information obtained in the three municipalities during the participatory workshops for constructing the typology. Relative strength for each criterion, according to the farm type: + (small); ++ (medium); +++ (large); NR (not relevant for the specific farm type).

	Agroecological Family Farmers	Traditional Family Farmers	Conventional Family Farmers	Part-Time Farmers	Large-Scale Farmers	Landless Farmers
Size of the farm	+	+	+	+	+++	NR
External inputs	+	+ / ++	++ / +++	++ / +++	+++	+++ ¹
Organic inputs	+++	+	+	+	+	+ ¹
Equipment and machinery	+	+	+ / ++	+ / ++	+++	+++ ¹
Market-oriented	+	+	++	+++	+++	+++ ¹
Distance to town	NR	NR	NR	+	NR	NR
Age of the main householder	NR	+++	NR	NR	NR	NR
off-farm income	+	+	+	+++	+	+
Resource endowment	+ / ++	+ / ++	+ / ++	+ / +++	+++	+
Land ownership	+	+	+	+	+	NR
Hired labour	+	+	+ / ++	++	+++	NR
Family labour	+++	+++	+++	+	+	+++
Participation in social organisations	+++	+	+	+	+	+
Forest conservation	++	+	++	+	+ / ++	+ / ++ ¹
Pastures with trees	++	+	+	+	+	+ ¹
Grazing intensity	+	+	+ / ++	+++	+++	+++ ¹
Intensive coffee weeding	+	++	+ / ++	++	++	++ ¹
Coffee with trees	+++	+	+	+	+	+ ¹
Presence of homegarden	+++	+++	++	+	+	+ / ++
Crop diversification	+++	++	+	+	+	+ / ++
Indigenous local knowledge	+++	+++	++	+	+	+ / ++ / +++

¹ In most cases landless farmers are subjected to the orders of the land owners.

3.2. Quantitative Typology

3.2.1. Multivariate Analysis and Farm Type Classification

The quantitative typology was based on a dataset comprising 115 full time family farmers owning land. Farmers were selected by the farmers' unions present in each municipality. Therefore, the other farmer types identified in the participatory exercise (i.e., large-scale, part-time and landless farmers) were not included. The first two axes of the PCA combined 48.1% of the variance in the dataset (Figure 3 and Supplementary Materials Figure S3), reflecting the inherent variability of farming systems. The variables number of public policies, number of CTA projects, number of crop products and number of agroecological practices were strongly negatively correlated ($R > 0.5$) with the first principal component (PC 1), while age of household head and farm area were strongly positively correlated ($R > 0.5$) with the second component (PC 2) (Supplementary Materials Table S4). The cluster analysis based on the first two PC axes grouped family farms in three clusters (Figure 3). The first cluster match agroecological farms ($n = 35$; 30.4%), with a positive correlation with number of crop products, adoption of agroecological practices and participation in extension projects and public policies (hypothesis i). The second cluster can be interpreted as traditional family farms ($n = 17$; 14.8%),

with a relatively high age of the household head and positioned in between the other clusters in the horizontal axis (hypotheses ii and iv). The third cluster match with conventional family farms ($n = 63$; 54.8%; Figure 3). The participatory-based hypotheses (i), (ii) and (iv) were confirmed by the multivariate analysis. However, the hypothesis that all family farm types had similar farm size (iii) was rejected, since large farm size was strongly correlated with traditional farms.

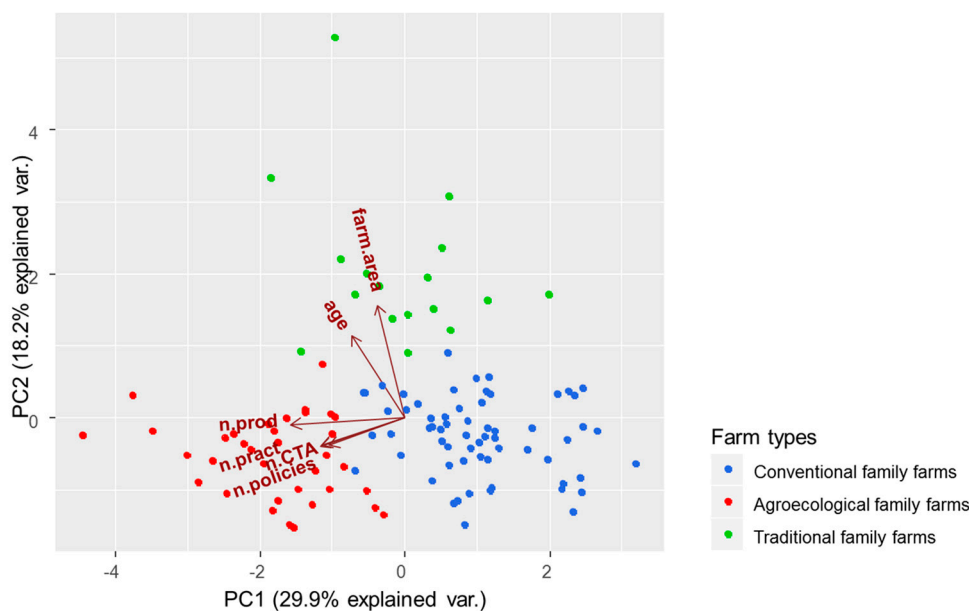


Figure 3. PCA output based on a dataset of 115 family farms. Colours indicate different farm types according to the cluster analysis classification (see text and Figure 4 for more explanation). *n.policies*—number of public policies in which households participated; *n.CTA*—number of extension projects from the local NGO (CTA) in which households were engaged; *n.prod*—number of crop products produced on the farm; *n.pract*—number of agroecological practices and principles adopted on the farm. *Age*—age of the household head, in years; *farm.area*—farm area, in hectares.

The agglomerative nesting process used to cluster the 115 farms (Figure 3) shows that, although the level of dissimilarity (or distance) between the clusters was quite high, three main groups of family farmers could be distinguished, in agreement with those identified through the participatory typology (Table 1).

The classification tree model used four of the six variables included in the analysis to separate the three groups of family farmers (Figure 4). Number of crop products (>23.5 crop products per farm) and participation in at least one CTA project were the emerging indicators to identify agroecological family farms, while larger farm area (either >7.75 or >16 hectares) and age of the household head (>38) were the indicators selected to distinguish traditional family farms from the other two types. Participation in public policies and number of agroecological practices adopted did not play a role at classifying farmers according to the binary tree model; yet these indicators were closely correlated with number of crop products and participation in CTA projects. In some cases, characteristics of conventional family farms and the two other farm types seemed to be relatively subtle. For instance, seven conventional farms had more than 23.5 crop products, but as they did not participate in any CTA project, they were classified as conventional farms. Moreover, five conventional farms had areas between the thresholds of 7.75 and 16 hectares, but were not classified as traditional farms because the age of the household head was less than 38 years.

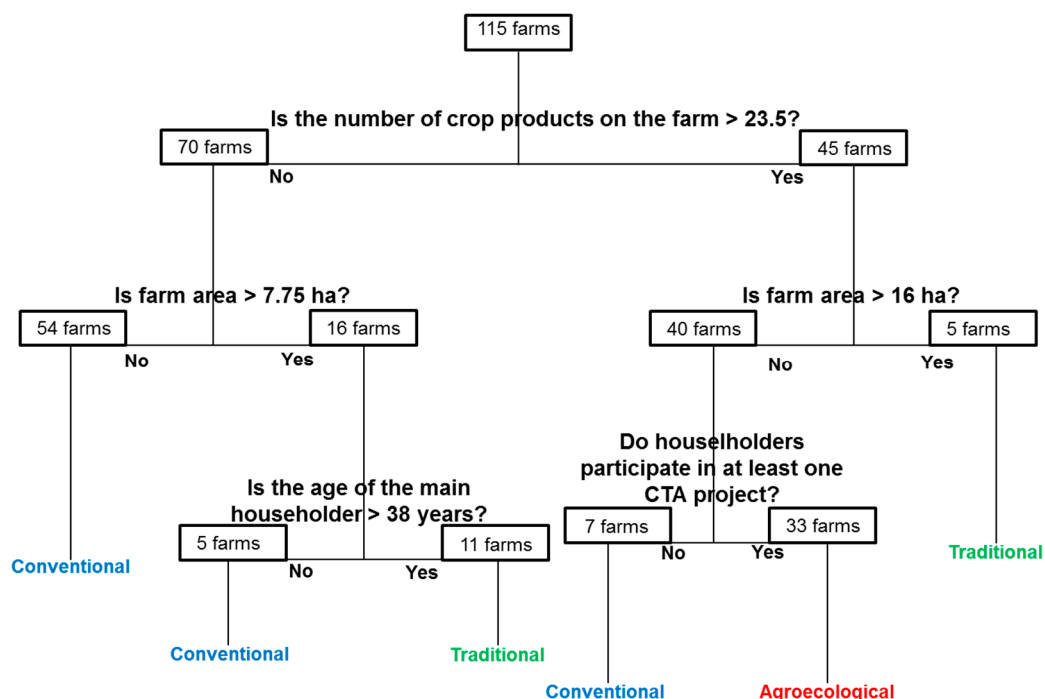


Figure 4. Tree model displaying threshold values for the classification of farm types based on the variables used in the multivariate analysis. The boxes represent the number of farms following (or not) the established criteria. The terminal nodes represent the final farm type classification according to the tree model. The misclassification error rate of the model is 0.06097 (7/115). CTA stands for Centre of Alternative Technologies of Zona da Mata, a local NGO working with family farmers.

3.2.2. Farm Types Characterisation

The proportions of farms that are beneficiaries of public policies (Pearson's Chi-squared test, $p < 0.01$) and CTA projects (Fisher's test, $p < 0.001$) were significantly different among farm types. All agroecological family farmers have participated in at least one project from CTA and almost 70% of agroecological family farmers benefitted from at least three to four public policies. On the contrary, the majority of conventional and traditional family farmers did not participate in CTA projects and had less access to the benefits of public policies. Almost one third of traditional family farmers did not participate in public policies and about 60% of the conventional family farmers had access to the benefits from one or two public policies (Supplementary Materials Tables S5 and S6).

Agroecological farms grew a larger number of crops (ANOVA, $p < 0.0001$), implemented more agroecological practices and principles (Kruskal-Wallis, $p < 0.0001$), and consumed a greater diversity of crops produced on farm (ANOVA, $p < 0.0001$) than conventional and traditional family farms (Figure 5). Traditional and conventional family farms have, however, adopted some agroecological practices and grow a lower, but still considerable, diversity of crops and of products consumed (Figure 5). Besides, the household head of agroecological family farms are significantly older (Kruskal-Wallis, $p < 0.0001$) than conventional family farmers (Figure 5), which suggests that younger farmers may be more inclined to follow a market-oriented production orientation. Finally, the differences among traditional and the other two family farm types indicated by the participatory typology were confirmed by significantly older household heads (Kruskal-Wallis, $p < 0.0001$) and larger farm sizes (ANOVA, $p < 0.0001$) associated with traditional family farmers (Supplementary Materials Tables S7 and S8).

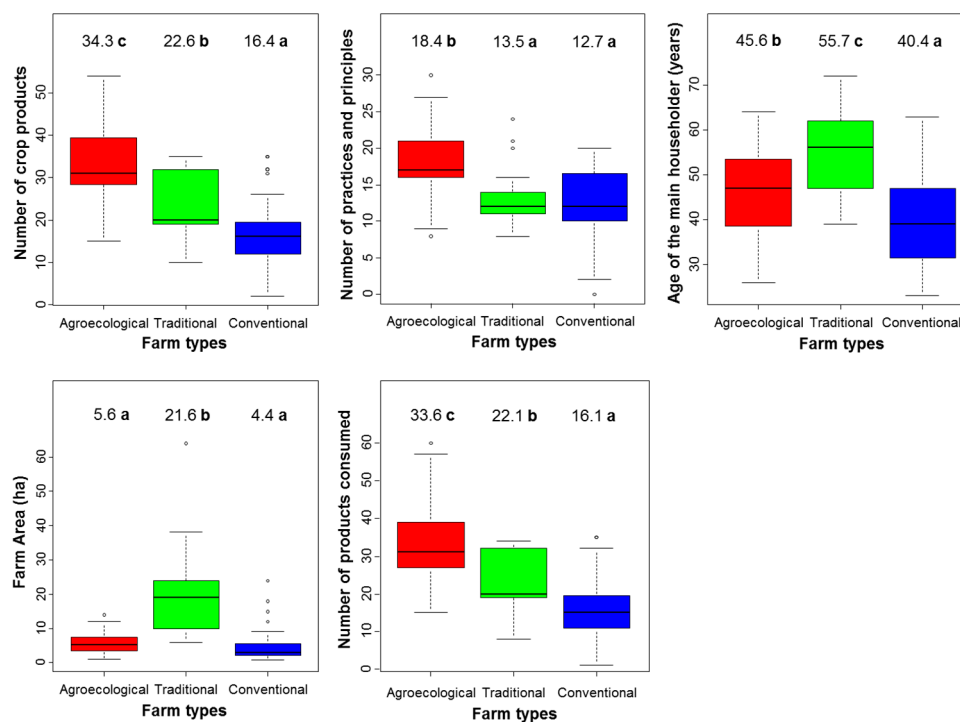


Figure 5. Boxplots of agroecological, traditional and conventional farmers for five farming system social characteristics. The black line that divides the box represents the median. The end of the boxes represents first and third quartiles, whiskers indicate the minimum and maximum values (excluding outliers) and outlier values are represented separately by the small circles. Mean values and letters indicating statistically significant differences are indicated above the boxplots. Age the household head and number of agroecological practices and principles were analysed using Kruskal-Wallis, and number of crop products consumed, number of crop products and farm area using ANOVA.

3.2.3. Association between Farm Diversity and Agroecological Practices and Principles

The neural network analysis showed variable degrees of association between agroecological practices and principles and the three types of family farms (Figure 6 and Supplementary Materials Table S9). Agroecological family farms appeared at the centre of the network, while conventional and traditional farms had a peripheral position, reflecting the expected general higher association of agroecological farms with all the practices and principles included in the analysis. Practices, such as composting, use of bio-fertilisers and alternative pesticides, cultivation of repellent plants, the presence of agroforestry systems, and local culture valorisation appeared on the upper left hand-side of the network. These socio-ecological indicators were more distant from traditional and conventional family farms and more closely associated with agroecological farms, indicating a more advanced stage of agroecological transition. Gender equity and group participation were also more closely associated with agroecological farms. There was a set of practices, such as the use of manure, exchange of labour days, family collaboration, use of landrace seeds, use and cultivation of medicinal plants and intercropping that were shared across the three family farm types. There were also practices (e.g., mechanical weed mowing or forest conservation) more commonly associated with conventional and agroecological family farmers than with traditional farmers. Moreover, alternative animal feeding to complement grazing and presence of on-farm scattered trees were more common among agroecological and traditional family farms than for conventional farms.

organisations, NGO's, local culture, and public policies were distinctive features of agroecological farms. This reinforces the idea that agroecology needs to be defined not only by practices, but also by principles and social relations.

4.1. Agroecological Practices and Principles

Family farmers differed in terms of farm management and adoption of agroecological practices and principles, and the association between these and the farm typology was revealed through the neural network analysis (Figure 6). The use of chemical fertilisers was common in all family farm types. Agroecological farms also adopted other practices to maintain soil fertility, including the use of compost, biofertilisers, and agroforestry. These practices reduce the need to apply chemical fertilisers and generate other benefits for the soil, such as increased organic matter content, reduced soil erosion and improvement of soil biological and physical quality [46,47]. Alternative practices for biological control were also more common in agroecological farms, such as the use of plant extracts to manage pests and diseases, and the cultivation of repellent plants [48,49]. Social capital was also stronger amongst agroecological farms, which is reflected in higher group participation and gender equity. Indeed, social capital may contribute to farmers' ability to self-organise, claim rights and access knowledge and information [50,51].

Some agroecological practices that have their roots in peasant traditions [13] are still present amongst family farms. They include intercropping, exchange of labour days, the use of landrace seeds and the use and cultivation of medicinal plants. Building upon these practices can be a good strategy for policies and extension services to support a process of agroecological transition, because farmers are already accustomed to, and have knowledge of them [52]. Alternative animal feeding practices and the presence of on-farm scattered trees are associated with the management of multi-species home gardens which are often encountered on traditional and agroecological farms. Home gardens are often managed without external inputs and supported by biodiversity-mediated processes and resources produced within the farming system, such as manure and plant residues. This makes farmers more autonomous in terms of producing food, both for self-consumption and for the market [53,54]. In addition, traditional knowledge about plants and animals is preserved and put in practice in home gardens [55]. Women manage home gardens and therefore play an important role in maintaining ancestral knowledge related to agroecological practices [56].

According to the participatory typology, the use of fire and intensive weeding were more common in traditional farms. Before the Green Revolution, these practices were considered beneficial for crop production, and fire was applied to reduce labour requirements [57]. Nowadays, some agroecological practices are also broadly adopted in conventional farms (e.g., mechanical mowing instead of uproot weeding), which can generate the same benefits as fire and intensive weeding, while reducing soil erosion and improving nutrient cycling and water conservation. Furthermore, conventional family farmers were more likely to conserve forest patches on their farms than agroecological and traditional farmers, probably because they acquired land that already contained forest. While currently there are strict laws that can penalise farmers for deforestation, family farmers are typically not motivated to restore new forest areas. Reforestation is a challenge for family farmers because of reduced land availability and little knowledge on restoration strategies and their possible benefits. While environmental laws are needed to maintain the reminiscent forest patches, these currently do not provide efficient incentives for smallholder farmers to restore land by managing native vegetation. For instance, farmers are discouraged to stimulate regrowth of native vegetation because they can be punished in case they need to cut or manage the trees in the future [58]. This indicates a need for (i) adjusted policies that better incentivise farmers to conserve native vegetation, in combination with (ii) an engagement process with farmers to understand and strengthen multiple ecosystem services derived from the forest, and (iii) the development of native vegetation management and conservation strategies that fit farmer's realities through extension programs and activities from the agroecological movement.

4.2. Farm Diversity and Implications for Agroecological Transitions

Farming systems in the Zona da Mata are inherently complex and diverse (Figures 5 and 6). Despite the aim of typology approaches to identify discrete groups, in reality farm diversity can best be understood as a continuum where different farm types can co-evolve, interact and overlap [59]. In fact, agroecological transitions may also be understood as a process in which farmers move along an infinite continuum, and it is therefore difficult to draw a sharp line that separates agroecological from non-agroecological farmers, as well as a specific end point of transition. In our study, this is evidenced by the fuzzy boundaries between conventional, traditional and agroecological farms (Figures 4–6). Indeed, there was great variation within each farm type, for instance in terms of the wide set of practices adopted by farmers in the same type. Nevertheless, farm types can be understood as reference points in the same continuum and our typology was able to make explicit the diversity of farming systems, and to reveal clear and useful general patterns that provide insights on how to assess and foster transition processes.

The quantitative typology showed that farms with converging characteristics that reflect high agrobiodiversity, food security and social engagement were statistically clustered in one type (Figures 3 and 6). Therefore, we can consider these farms to be more advanced in the agroecological transition process and to have a presumably high potential for the provision of a wide range of ecosystem services [60]. By engaging with social organisations, family farmers may be able to share and access knowledge and participate in interactions with other stakeholders which can foster the transition towards more agroecological systems [61,62]. In Zona da Mata, farmers categorised as agroecological, who in the past were either landless, conventional or traditional family farmers, were part of a social movement and a network that brought together farmers, church-based organisations, local NGOs (CTA), the Federal University of Viçosa, and other organisations [12] (Table 1 and Figure 3). Through this movement, they were able to contest the mainstream discourse of the Green Revolution and construct an alternative agroecological discourse that recognises farmers' own knowledge and resources [11]. Through this movement, traditional practices were revalued and new agroecological practices constructed through on-farm experiments, participatory research and peasant-to-peasant learning exchanges [12,31].

The movement also allowed farmers to participate and co-construct a variety of public policies, including the Land Credit Policy, the Food Acquisition Programme and the National School Feeding Program (Figure 3). These policies enabled farmers to access land and to create local markets that gave more value to agroecological products [63]. The maintenance and development of adequate policies and funds to better support more sustainable and equitable food systems could accelerate the expansion of agroecological networks and activities [64]. For instance, the significant lower age of the household head of conventional compared to agroecological family farmers (Figure 5) indicates the need to support young farmers in the process of transitions, providing them access to credit and ecologically-based extension services.

Amongst family farms, the traditional farms were led by older household heads that tended to hold larger areas of land (Figure 5), as the heritage process resulting in the division of the land to their heirs was not yet concluded. In our study the average farm size of family farms was 7.3 ha, while data from the national census show that the average farm size in the three municipalities is 9.3 ha for family farmers and 47.10 ha for non-family farmers [36]. Our results suggest that traditional family farmers could be an important target of agroecological transitions as they have heirs who will take their place in the farm and still hold many peasant characteristics that are supportive of agroecology, such as indigenous knowledge, strong community networks, high agrobiodiversity, conservation of landrace seeds and food self-sufficiency [65] (Table 1, Figures 5 and 6).

Both part-time and large scale farmers appeared as a less suitable target for agroecological transitions, because of their view on nature as a commodity [19], as well as strong market-orientation and economical focus. However, large scale and part-time farmers can still be motivated to adopt agroecological practices that have no negative impact on cash crop production. For instance, reducing

the use of chemical pesticides, mowing instead of intensive weeding, abandoning the use of fire and implementing water harvesting structures may be considered interesting by more market-oriented farmers. However, adoption of these practices will only result in a small transition shift, as it does not include social, cultural and organisational aspects that are also part of agroecology [66].

Farmers only made significant advances towards agroecology once they had legal land rights [67]. Several agroecological farmers acquired land through the government's Land Credit Policy [68] and through locally organised arrangements that purchase land collectively [69]. The importance of policies and movements that promote land rights, such as the Land Credit Policy, need to be re-affirmed nationally and internationally, as these policies are being dismantled and movements criminalised by the current government. The landless movement is also present in the Zona da Mata region and requires support as a way to promote an agrarian reform. Brazil is one of the countries with the greatest land concentration in the world which is associated with negative externalities, such as rural poverty and social exclusion [68]. Critically, access to land should be followed by programmes that allow farmers to exchange and acquire knowledge of agroecological farming. Otherwise there is a risk that these farmers will follow the principles set by the dominant discourse on market-oriented agriculture [70].

4.3. Typology Construction for Agroecological Transitions

To our knowledge, this is the first study that developed farm typologies specifically to understand and analyse a long-term process of agroecological transition, focusing on changes at farm level. Following previous research in the region [12,38], we used participatory methods to interest farmers to participate in a collective process of co-creation of knowledge [31]. This was also important to generate a collective understanding of agroecology. This collective understanding is relevant to increase awareness about agroecological ideas, farms and practices, as well as to identify opportunities and barriers for promoting agroecological transitions [71]. Participating farmers reported that the process allowed them to better understand and reflect upon their own reality, which may have implications for their future management choices. The outcomes of the participatory typology did not always match with empirical statistics. For instance, the proportion of family farmers in Zona da Mata in our study (54.1%) was lower than reported in the national census (82%). This discrepancy can be explained by the fact that landless farmers were considered as a separate category in our participatory workshops and not in the national census. The number of landless farmers in the national census is also probably underestimated, due to difficulties to interview rural workers who do not own land. While our participatory approach allowed the collection of detailed context specific data, it was based on the perceptions of farmers, which does not necessarily accurately represent the reality.

The participatory typology offers a qualitative, broad and holistic view on farm diversity, typical of indigenous knowledge systems [72], while the statistical typology takes a relatively reductionist approach based on a few variables. Nevertheless, the quantitative analysis allowed the further exploration and testing of the general patterns that emerged from the participatory typology. The outcomes of the quantitative analysis brought insights about the relationships between farm structural and social variables and the position of farmers on a transition continuum among conventional, traditional and agroecological systems. Although the tree classification model provided useful quantitative information on thresholds to be used as reference values for further categorisation and/or monitoring of agroecological transitions, it should be examined carefully, as farm types featured great variation and fuzzy boundaries. The only major discrepancy between the categorisation made by the two approaches was the farm size among family farmers. In the quantitative typology, farm size was higher in traditional than in the two other family farm types. In contrast, no differences on farm size among family farmers were shown in the participatory workshops, probably because the differences between family and large-scale farms were much more prominent, or because farmers do not perceive this variable as relevant. We also suggest that quantitative variables that reflect participation in social networks must be considered in future studies on agroecological transitions. In our case, although the

variable “*n.CTA*—number of extension projects from CTA in which households were engaged” was endogenous to our own data set, it represents the engagement of farmers in a network, or a movement. Although our effort is a first step towards identifying and developing indicators that account for social and network engagement, we recognise the limitation of the variable “*n.CTA*” as there are different ways and degrees for participating in a movement. The level of participation or engagement needs to be better captured as we have shown that it plays an important role in agroecological transitions.

5. Conclusions

We combined participatory and quantitative methodologies to highlight contrasting characteristics among farm types, including differences in terms of farmers’ agroecological practices and principles. Our study revealed how farmers perceived the different types of farms in the region and what are the implications of farm diversity for the strategies to promote agroecological transitions. Our main findings are:

- (i) In the face of agroecological transitions, farmers differ in their management strategies, practices and principles;
- (ii) Farmers identified as agroecological were strongly engaged in a network composed of farmers’ organisations, universities and NGO’s;
- (iii) Agroecological farms showed great potential to provide a wide range of ecosystem services as they featured higher crop diversity and higher number of crops for self-consumption;
- (iv) To promote agroecology, it is crucial to recognise peasant knowledge and change the dominant discourse on agriculture through social movement dynamics, as well as to generate support from public policies and funds; and
- (v) Participatory and quantitative methodologies can be combined for more precise and relevant assessments of agroecological transitions

To further assess why and how each agroecological practice is adopted, indicators of the intensity of adoption need to be developed. Future work should address how agroecological practices and principles are constructed and disseminated, considering infra and supra-household drivers, interconnections among social and ecological variables, as well as the influence of organisations, local culture and knowledge. The promotion of agroecological transitions must place farmers and their knowledge at the centre. In addition, farmer organisations, scientists, policy-makers and technicians must get together to facilitate knowledge exchange and dissemination, as well as to incorporate agroecology in national and international political agendas towards more equitable, sustainable and autonomous agriculture and food systems.

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