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Multicriteria analysis of the sustainability performance between agroecological and conventional coffee farms in the East Region of Minas Gerais (Brazil)

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Abstract

The goal of this study is to perform a comparative analysis of agroecological and conventional small coffee farms. We investigated 15 coffee farms in the East region of Minas Gerais, a Brazilian rural region, based on coffee production using a multicriteria analysis with economic, social and environmental factors. The results suggest that agroecological farms perform better than conventional farms in terms of sustainability, reduce labor intensity and improve income stability and the environmental impact, such as agro-biodiversity and forest cover. In particular, the results reveal that agroecological farms, though they have lower levels of coffee productivity than conventional farms, perform better in terms of income stabilization. This result depends on product diversification (such as agri-food products, vegetables or fruits) for local markets, which reduces farmer risks associated with coffee price volatility, improving both the local economy and local food security. Moreover, agroecological farms rely more on labor than capital. Overall, the results of this study reveal that agroecological systems support the socio-economic sustainability of the rural areas under study and suggest the potential of agroecology to boost sustainable development in the East Region of Minas Gerais. In short, the spread of agroecological systems could improve local employment conditions, reducing migration toward large cities and shanty towns in other parts of Brazil. Hence, agroecology systems can represent the main alternative to conventional production systems to improve the well-being and wealth of rural populations in developing countries. The analysis presented in this study is based on a specific case study, but the rural area under study has many similarities with other areas in Latin America regarding all aspects of economic, social and environmental sustainability. Finally, some agricultural policy implications are discussed.

Introduction

Since the Earth Summit held in Rio de Janeiro in 1992, the international community has declared the necessity of finding a sustainable approach to agriculture in which small farmers can play a critical role in food production to reduce environmental impacts and support sustainable rural development in poor countries (cf., Agenda 21, 1992). In this context, agroecology has been recognized internationally as a possible approach that can improve socio-economic and environmental conditions in many rural areas of developing countries (Pretty *et al*., 2006; Wezel *et al*., 2009). Agroecology is the application of ecological science to the study, design and management of sustainable agroecosystems to improve the production and resilience of agroecosystems to external shocks and reduce their dependency on external inputs, such as fertilizers, pesticides, energy or human control (Gliessman, 1990; Altieri and Nicholls, 2005). The main agroecological practices are no-tillage, intercropping, agroforestry, crop rotation and all agronomic or traditional techniques that reduce the need for energy and increase biological interactions within the agroecosystem components (Altieri and Toledo, 2011). Agroecology also represents a new approach based on sustainability to cope with the looming climatic and ecological challenges of countries (Elver, 2015), generating important spillovers in restoring local natural resources supporting local ecosystems and biodiversity (FAO, 2018).

Although there is a vast literature on agroecology (Wezel and Soldat, 2009), many studies have analyzed agroecology effects considering only single factors of sustainability and mono-dimensional approaches. In addition, the difficulties in obtaining observable data have led to a lack of empirical works with manifold dimensions that analyze the impact of agroecology in society and the environment.

The goal of this study is to perform a comparative analysis between agroecological and conventional coffee farms in the East region of Minas Gerais (MG), a Brazilian rural region, using a multicriteria analysis (MCA) to assess farm performance in terms of sustainability and socio-economic effects. We present in the next sections the theoretical framework, study design and results of this paper with implications for sustainable production in rural areas.

Theoretical framework and working hypotheses

Sustainability is a multidimensional concept based on people (social aspect), the planet (environmental aspect) and growth (economic aspect) and is appropriate for analyzing rural areas in developing countries in a holistic way (Hansmann *et al.*, 2012). Agroecology is a concept strictly related to the concept of sustainability with the main effects on economic growth, environmental conservation and intergenerational equity. Many scholars argue that agroecology is a basic strategy for long-term food system sustainability and security (Francis *et al.*, 2003; Watts *et al.*, 2005). In particular, agroecological systems are growing in rural regions of Brazil, Bolivia and many other Latin American countries based on smallholder farmers (da Costa *et al.*, 2017). In fact, smallholder farms in developing countries are keys to food security, sustainable economic growth and poverty reduction (Altieri, 2002; Altieri *et al.*, 2012; Goswami *et al.*, 2017). In general, agroecological approaches are adaptable to both the particular ecological characteristics of every bioregion and the socioeconomic needs of the communities dwelling in the territory (Levkoe, 2018). Various studies have demonstrated that small and medium-scale agroecological farming can be more productive, efficient and sustainable than large-scale industrial farming (Pretty *et al.*, 2006; Levkoe, 2018).

In this context, mono-dimensional approaches of analysis can overlook important aspects of sustainability and agroecology, whereas holistic approaches can consider a multifunctional view of agricultural production (Wei *et al.*, 2010). Several scholars argue the limitations of the application of single indicators and that this methodological issue can be solved with systemic measurements and analyses (Gómez-Limón and Sanchez-Fernandez, 2010; Peano *et al.*, 2015). The systemic approach provides comprehensive analyses to explain the relationship of sustainability concerning single farms, rural areas, regions or countries (van Asselt *et al.*, 2014). This systemic approach can be based on synthetic measurements that encompass all factors in a balanced way (cf., Bossel, 2002; Paracchini *et al.*, 2015; Peano *et al.*, 2015; de Olde *et al.*, 2016). MCA has been applied to compare farming systems individually to assess farm performance in terms of sustainability (Triantaphyllou, 2000; Figueira *et al.*, 2005). MCA is a part of operational research, and its strength is its high adaptability to different problems to perform comparative analyses of incommensurable attributes, which are typical pitfalls encountered in sustainability measurements (Cinelli *et al.*, 2014). In particular, MCA divides the problem under analysis into hierarchies, creating categories, subcategories and attributes (Cinelli *et al.*, 2014), and some studies related to sustainability assessment in agriculture apply similar approaches to MCA (cf., Peano *et al.*, 2015). This method is strictly linked to the same approach of sustainability assessment in applied economic analyses in rural studies, which divides the analysis by the dimension, sub-dimension and indices of farm sustainability (e.g., Peano *et al.*, 2015). MCA is a consistent method for integrating sustainability spheres and considering their interdependencies (Huang *et al.*, 2011; Cinelli *et al.*, 2014).

Material and methods

Research setting

Brazil is the largest producer of coffee worldwide (ICO, 2020), and almost half of the Brazilian green coffee comes from the state of MG, where coffee is mainly cultivated by small farmers, representing 80% of the total agricultural units of MG (MAPA, 2015). In this study, five municipalities of the Eastern region of MG were considered: Simonesia, São João do Manhuaçu, Conceição de Ipanema, Caratinga and Manhuaçu. Coffee production is the most important economic activity of those municipalities[1], and in this area, small farming is the backbone of the agricultural sector, representing 85% of total farms (IBGE, 2006, 2010). The biome of the area is Atlantic Forest, which is highly endangered by anthropic activities linked to agricultural expansion driven mainly by coffee production, one of the major causes of forest fragmentation and habitat loss in the area (Ferrari and Diego, 1995; Tabarelli *et al.*, 2005).

In this area, some farmers undertake a transition from conventional practices to agroecology, increasing the complexity of agroecosystems (see Altieri and Rosset, 1996; Altieri, 2002).

Sample

A total of eight farmers undertook a transition longer than 3 years, sustained by an international cooperation project, and they were selected as case studies for our analysis (Pronti, 2018a). Considering the limited number of agroecological farms in the area (i.e., eight), all of these farms were entered into the analysis and represent the group of *agroecological farms*. To be considered agroecological, a farm should adopt sustainable practices for a minimum of 3 years, such as agroforestry, intercropping, no-tillage, integrated pest control, no use of pesticides, reduction of chemical fertilization and crop rotation (Kerr *et al.*, 2018). The use of chemical inputs was not considered to be an excluding restriction, as some agroecological farmers still relied on fertilizers (even if in small amounts) as they were in the transition phase from conventional to agroecological practices.

Conventional farms were selected as a group of farms belonging to the local coffee farm association, as suggested by local agronomists, by considering similarities in terms of their economic activity and farm size and geographical distributions relative to the group of agroecological farms. A total of seven conventional farms were included in the study and formed the counterfactual group.

Hence, the final sample under study included 15 farms as follows:

- Eight agroecological farms
- Seven conventional farms

In addition, 13 farms were considered to be smallholders (average utilized agricultural area (UAA) = 5.75 ha), whereas two farms were considered to be medium–large (UAA ⩾30 ha).

Data collection

The study was based on the direct data collected by field visits and semi-structured interviews considering the social, economic and environmental characteristics of the farms. Farmers were

[1]Including employment (60% of the population is employed in agriculture), the regional economy (97% of the value of total production is from coffee value chains) and land use (99% of the cultivated lands are coffee fields) (IBGE, 2010).

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introduced to the researchers during the activities of international development projects carried out in the region (see Pronti, 2018a, b). Farm visits were made before the interviews with the aim of both establishing a trusting relationship with the farmers and having a first-hand understanding of the specificity of each agroecosystem. Interviews were based on a semi-structured method and lasted, on average, 3 h, including questions related to social, economic and environmental dimensions. At the end of the interview, farmers could integrate and describe the peculiarities of their farm systems. Before starting the analysis of data, the information collected was verified by the farmers themselves and validated by local agronomists and rural development experts (cf., Lopez-Ridaura *et al.*, 2002). Moreover, the economic data were assessed using official datasets and reports from the main Brazilian institutions related to farming, coffee production, livestock and agri-food products, such as the Brazilian Ministry of Agriculture and other national agricultural agencies (e.g., Ministry of Agriculture, Embrapa, Ceasa Minas, Conab, and Cepea[2]). Unavailable data were collected locally. All data were standardized to UAAs or as percentages for comparability.

Methods and data analysis procedure

The MCA method used was the multi-attribute utility theory considering different aggregator methods to ensure robust results (Cinelli *et al.*, 2014). At the beginning of the analysis, several indicators of performance, all of which were related to the three main dimensions of sustainability (economic, social and environmental) of the farming systems, were considered.

The indicators applied were related to input use, production and yields; profit; income stability; revenue diversification; return to labor and land; agrobiodiversity and forest conservation. All of the indicators were divided into different dimensions (economic, social and environmental)[3].

This study considers three different dimensions of sustainability related to economic, social and environmental aspects. A selected subset of the indicators identified was used, combining them under their specific dimension and dividing them into sub-dimensions (called criteria in the MCA literature), which were measured through single indicators (called attributes in the MCA literature) using only the most representative ones collected during the survey and avoiding double counting and redundancy of measurements (Figueira *et al.*, 2005).

After obtaining the first list of all the indicators, they were reviewed and divided into different groups to be considered as criteria of each sub-dimension to describe sub-categories of the main dimensions (economic, social and environment), such as solving a preliminary part of a multicriteria problem (Figueira *et al.*, 2005; Zarghami and Szidarovszky, 2011). The three main dimensions were subdivided into nine sub-dimensions: four for economic (productivity, income creation, income stability and input efficiency), two for social (labor and income diversification), and three for environmental dimensions (agro-biodiversity, forest cover and use of chemical inputs). At the end of the process, the analysis of farm sustainability was divided into three main dimensions, nine sub-dimensions and 14 attributes measured with ad-hoc indicators. The data were standardized following the distance method proposed by Zarghami and Szidarovszky (2011) and Durbach and Stewart (2012). Then, weights were selected to consider the three levels of the informative layers in an egalitarian way among the three main dimensions (Zarghami and Szidarovszky, 2011).

The dimensions, sub-dimensions and indicators with their weights are listed in Table 1.

Thereafter, all the indices in standardized form were aggregated using three different methods for a robust unique measurement of the multidimensional performance of sustainability in coffee production. All the data related to the selected variables were inserted into the farm performance matrix $A_{i,j}$, which contained the performance of all the farms for each attribute in which the values $a_{i,j}$ represent all the jth attributes for each ith farm measured with a specific indicator. The performance matrix $A_{i,j}$ was normalized in $\bar{A}_{i,j}$ following the distance method proposed by Zarghami and Szidarovszky (2011). Normalization of the values is needed to reduce differences in units of measurements and the magnitudes of the different attributes measured by very different indices with different scales and meanings. The elements of $\bar{A}_{i,j}$ were calculated as follows:

$$\bar{a}_{i,j} = \frac{a_{i,j} - a_j^-}{a_j^* - a_j^-}$$

where $a_{i,j}$ are the values of the performance matrix; a_j^* is the best value in all the performance matrixes of the jth attribute (the ideal point); and a_j^- is the worst value in all the performance matrixes for the jth attribute (nadir point or negative ideal point). After normalization, matrix $\bar{A}_{i,j}$ represents the non-dimensional distance of $a_{i,j}$ from the best and the worst performance for each jth attribute in the sample. All the indicators were divided into positive and negative groups, the former increasing as its value increases (e.g., profits or environmental benefits), whereas the latter increases as its value decreases (e.g., costs or environmental impacts). We considered this aspect during the normalization phase by simply inverting the reference levels of the ideal and nadir point solutions (Department for Communities and Local Government, 2009). In MCA methods, weights are used to divide the importance of each indicator in the final assessment of each alternative score. In the classical MCA, weights reflect the stated preference of the decision-maker over the different attributes of the different alternatives (Durbach and Stewart, 2012). These weights are important elements for model calibration because in the final data aggregation, the weight distribution can alter the final results.

In this analysis, weights were selected following an egalitarian approach (Zarghami and Szidarovszky, 2011). The value of 1, which is the sum of the total weights, was first divided by 3 considering the main levels, obtaining 0.33 as the weight of each dimension. Then, the same process was repeated for each sub-dimension, dividing the value of 0.33 (the weight of each dimension) by the n-number of the sub-dimensions within a single dimension. The same was done for the single indicators by dividing the weight of each sub-dimension by the m-number of indicators for each component and sub-component of the analysis until arriving at the final division of weight (Table 1), creating the vector W_j, in which w_j is used to weight the jth attribute.

[2]Embrapa (*Empresa Brasileira de Pesquisa Agropecuária* in English Brazilian Agricultural Research Corporation, Ceasa Minas (*Centrais de Abastecimento de MG* in English MG Supply Centers), Conab (*Companhia Nacional de Abastecimento* in English National Supply and Stocking Company), and Cepea (*Centro de Estudos Avançados em Economia Aplicada* in English Center for Advanced Studies on Applied Economics).

[3]For the details of the list and the calculations of the indicators and measures of the performance of the agro-ecological and conventional farms divided by dimensions, see the Supplementary Materials Section Measurements.

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Table 1. Dimensions, sub-dimensions and indicators selected and used in the MCA analysis.

Dimensions	Sub-dimensions	Indicators, w = weight
Economic dimension 1 (weight = 0.333)	Sub-dimension 1.1 productivity (weight = 0.25)	Indicator 1.1.1 (w 0.083) average coffee production for UAA of coffee (+)
	Sub-dimension 1.2 input efficiency (weight = 0.25)	Indicator 1.2.1 (w 0.042) % variable costs on total revenues for UAA (−)
		Indicator 1.2.2 (w 0.042) % of chemicals costs on variable costs (−)
	Sub-dimension 1.3 income stability (weight = 0.25)	Indicator 1.3.1 SD (§) among different net present value (NPV) of the three coffee price scenarios (−)
	Sub-dimension 1.4 income creation (weight = 0.25)	Indicator 1.4.1(w 0.042) net agricultural income (R$) of the farm (+)
		Indicator 1.4.2 (w 0.042) net agricultural income per UAA (R$/ha)[a] (+)
Social dimension 2 (weight = 0.333)	Sub-dimension 2.1 labor conditions (weight = 0.5)	Indicator 2.1.1 (w 0.083) labor intensity per UAA (h worked/ha) (−)
		Indicator 2.1.2 (w 0.083) return to labor (R$/h worked) (+)
	Sub-dimension 2.2 income diversification (weight = 0.5)	Indicator 2.2.1 (w 0.0167) revenues diversification % of cash crop on total revenues (−)
Environmental dimension 3 (weight = 0.333)	Sub-dimension 3.1 diversity (weight = 0.333)	Indicator 3.1.1 (w 0.11) agrobiodiversity no. of cultivated species (+)
	Sub-dimension 3.2 forest conservation (weight = 0.333)	Indicator 3.2.1 (w 0.11) % of forest area on total property (+)
	Sub-dimension 3.2. Use of chemicals (weight = 0.333)	Indicator 3.3.1 (w 0.04) quantity of chemical fertilizers used per UAA (kg/ha) (−)
		Indicator 3.3.2 (w 0.04) quantity of soil correctors per UAA (kg/ha) (−)
		Indicator 3.3.3 (w 0.04) quantity of chemical pesticides per UAA (kg/ha) (−)
Total weight (w) = 1.00		

Notes: In parenthesis weights of each component: (+) indicates a positive indicator, (−) indicates a negative indicator. (§) It has been calculated as the SD of the three scenarios (pessimistic, optimistic and regular) of the cost benefit analysis (CBA) (see Supplementary Materials). It measures the entity dispersion of the values, the higher its value the more dispersed around the mean the outcome is. We considered as lower levels of SD were better (negative). The formula is $SD_i = \sqrt{(x_i - \bar{x})/n}$, where x_i is the scenario of each farmer, $\bar{x}$ is the average value of the scenario of the farmer and n is the number of scenarios (in our case $n = 3$).
[a]It represents the ability of the farmer in producing income for each plot of land he/she uses.

The weighted sum method (WSM) (Keeney, 1982), the weighted product method (WPM) (Triantaphyllou, 2000; Zarghami and Szidarovszky, 2011) and technique for order of preference by similarity to ideal solution (TOPSIS) (Opricovic and Tzeng, 2004) were used as different aggregation methods.

The aggregation methods were calculated as follows:

- *WSM*: $A^*_{i\,\text{wsm score}} = \sum_{j=1}^{n} w_j \times a_{i,j}$. The selection rule is to choose the maximum $A^*_{i\,\text{wsm score}}$ obtained among the different alternatives which represents the best solution (Keeney, 1982).
- *WPM*: $A^*_{i\,\text{wpm score}} = \prod_{j=1}^{n} (a_{i,j})^{w_j}$. The selection rule is to choose the maximum $A^*_{i\,\text{wpm score}}$ obtained among the different alternatives, which represents the best solution (Triantaphyllou, 2000; Zarghami and Szidarovszky, 2011).
- *TOPSIS*: This method uses the Euclidean distance of the value of the attributes from the ideal point. The concept of TOPSIS is that the best alternative is the one with the closer distance from the ideal solution and the farthest distance from the nadir point (negative ideal solution) (Triantaphyllou, 2000; Opricovic and Tzeng, 2004). The TOPSIS method uses two different weighted normalizations of data before computing the final score of each alternative. In this study, the method proposed by Zarghami and Szidarovszky (2011) was used as follows:
  - The first normalization is for the distance from the nadir point (which is equal to that used previously in WSM and WPM):

$$a^-_{i,j} = \frac{a_{i,j} - a^-_j}{a^*_j - a^-_j}$$

  where $a^-_{i,j}$ is the distance of $a_{i,j}$ to the nadir point a^-_j.
  - The second normalization is the distance from the ideal point

$$a^*_{i,j} = \frac{a^*_j - a_{i,j}}{a^*_j - a^-_j}$$

  where $a^*_{i,j}$ is the distance of $a_{i,j}$ to the ideal point a^*_j.
  - Then, $a^-_{i,j}$ and $a^*_{i,j}$ are weighted using w_j, summed and square rooted, obtaining the two measures of the overall distance of the ith alternative from both the ideal and nadir points

$$D_i = \sqrt{\sum_{j=1}^{n} (w_{i,j} \times a^*_{i,j})^2}$$

$$d_i = \sqrt{\sum_{j=1}^{n} (w_{i,j} \times a^-_{i,j})^2}$$

  - Then, the relative closeness to the ideal solution F is calculated as

$$F_i = \frac{d_i}{(D_i + d_i)}$$

where the alternatives are ranked considering increasing F_i. The alternative with the highest F_i is then chosen as the best alternative over the others.

Results

Agroecological farmers on average show higher levels of sustainability in all the dimensions considered according to all the MCA methods of aggregation adopted. Agroecological farmers have better sustainability performances both improving socioeconomic conditions and the quality of the environment than conventional farmers, as shown in Figures 1 and 2. Agroecological farmers use on average less productive area per UAA (coffee, other products and forestry) than conventional farmers, reducing also the labor intensity, which is half that of conventional farmers. This effect can be due to the use of conventional practices based on a high intensity of labor and control of the agroecosystem, which is efficient only with large economies but not with reduced extension of the land.

The average coffee outputs of agroecological farmers are lower than conventional farmers, but the agricultural income per UAA is higher for them and more diversified than for conventional farmers, who rely solely on only coffee production for income generation. This result is due to the lower level of total variable costs paid by agroecological farmers than conventional farmers, especially for their external workforce and chemical products high costs. Agroecological systems, through reduction of costs, generate high levels of efficiency in resource use (capital, natural capital and labor), and they have good levels of income stabilization. The income generated by agroecological systems is more stable than conventional farming because of the higher level of diversification of production, which frees farmers from income instability generated by coffee price fluctuations. This diversification of revenue allows agroecological farmers to be more resilient to coffee price volatility than conventional farmers, diversifying their production into alternative productions for local markets or processed products. Moreover, this diversification contributes to dietary improvements and food security of the family.

The working activities of agroecological systems require less time for crop control than conventional systems, leaving spare

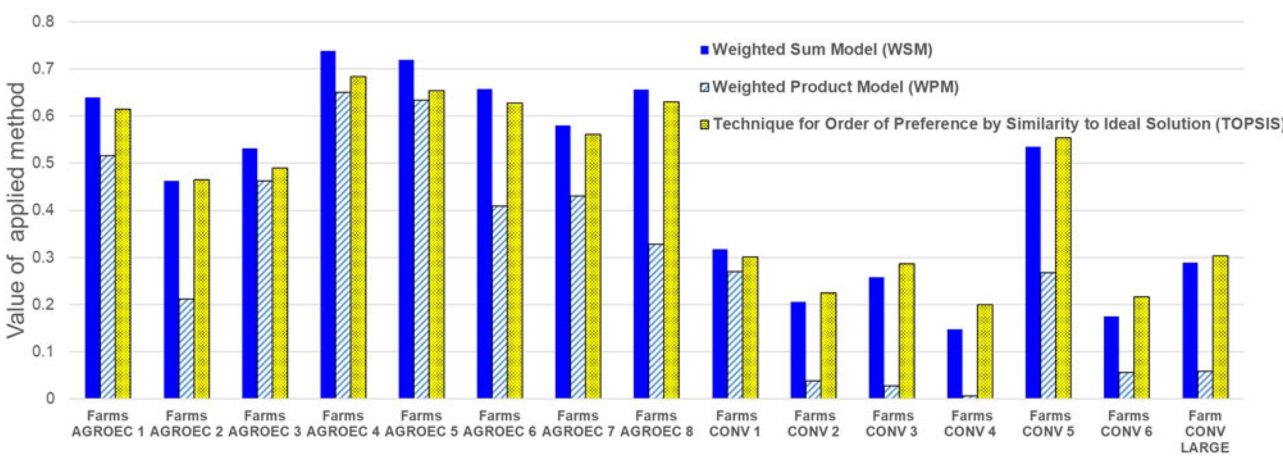

Fig. 1. Final scores of farmers with the WSM, WPM and TOPSIS.

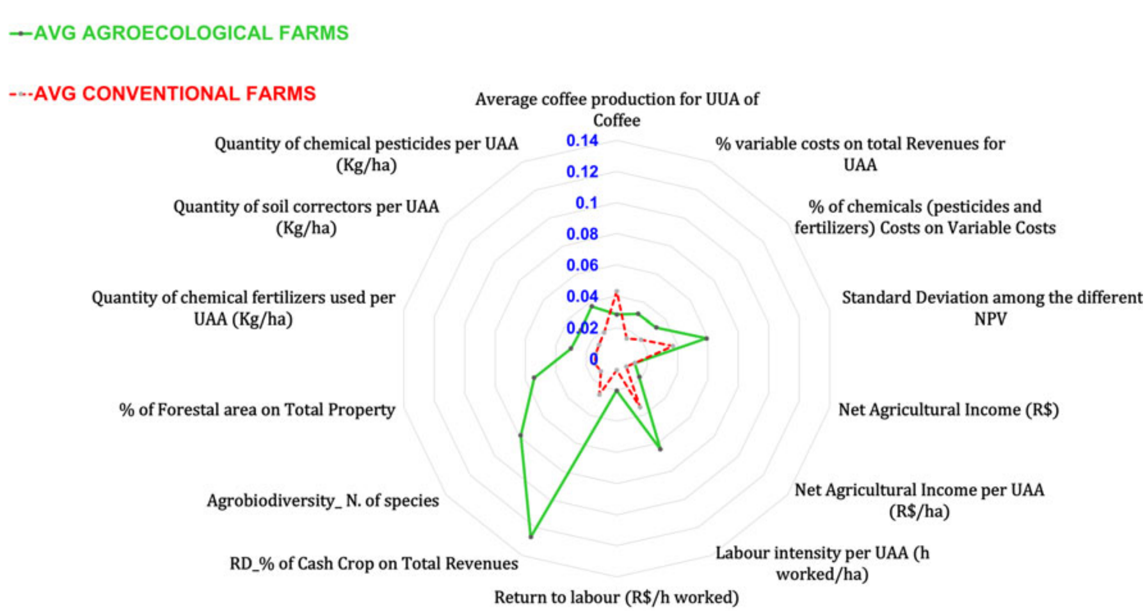

Fig. 2. Levels of sustainability of agroecological and conventional farmers based on the average of the indicators.

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Table 2. Final ranking of different methods of MCA.

Rank	Farm	WSM	Farm	WPM	Farm	TOPSIS
1	AGROECOLOGICAL 4	0.738	AGROECOLOGICAL 4	0.650	AGROECOLOGICAL 4	0.683
2	AGROECOLOGICAL 5	0.719	AGROECOLOGICAL 5	0.634	AGROECOLOGICAL 5	0.654
3	AGROECOLOGICAL 6	0.658	AGROECOLOGICAL 1	0.516	AGROECOLOGICAL 8	0.630
4	AGROECOLOGICAL 8	0.656	AGROECOLOGICAL 3	0.462	AGROECOLOGICAL 6	0.627
5	AGROECOLOGICAL 1	0.640	AGROECOLOGICAL 7	0.430	AGROECOLOGICAL 1	0.615
6	AGROECOLOGICAL 7	0.580	AGROECOLOGICAL 6	0.409	AGROECOLOGICAL 7	0.561
7	CONVENTIONAL 5	0.535	AGROECOLOGICAL 8	0.328	CONVENTIONAL 5	0.555
8	AGROECOLOGICAL 3	0.532	CONVENTIONAL 1	0.270	AGROECOLOGICAL 3	0.490
9	AGROECOLOGICAL 2	0.462	CONVENTIONAL 5	0.268	AGROECOLOGICAL 2	0.465
10	CONVENTIONAL 1	0.318	AGROECOLOGICAL 2	0.212	CONVENTIONAL LARGE	0.304
11	CONVENTIONAL LARGE	0.289	CONVENTIONAL LARGE	0.058	CONVENTIONAL 1	0.301
12	CONVENTIONAL 3	0.258	CONVENTIONAL 6	0.057	CONVENTIONAL 3	0.287
13	CONVENTIONAL 2	0.206	CONVENTIONAL 2	0.039	CONVENTIONAL 2	0.225
14	CONVENTIONAL 6	0.175	CONVENTIONAL 3	0.028	CONVENTIONAL 6	0.217
15	CONVENTIONAL 4	0.148	CONVENTIONAL 4	0.007	CONVENTIONAL 4	0.200

Notes: weighted sum model (WSM); weighted product model (WPM); technique for order of preference by similarity to ideal solution (TOPSIS).

time for leisure or other remunerative activities and providing room for additional profitable activities of the family. Moreover, the remuneration of work is higher for agroecological systems than conventional systems because of the high revenue generated per unit of work. The environmental dimension is definitively better for agroecological farmers than for conventional farmers because of the low levels of chemicals used in production activities. Forest cover is also higher for agroecological farmers than conventional ones. Agrobiodiversity, which is strictly related to the high level of product diversification of agroecological farmers, is also higher than in conventional farming. Overall, the results suggest the better sustainability of agroecological farmers than conventional ones from a systemic perspective.

The rankings of each aggregation method are shown in Table 2 with stable results among all the aggregation methods adopted (i.e., WSM, WPM and TOPSIS). Agroecological farmers consist of the top six ranks in the ranking of sustainability performance. One farmer, AGROECOLOGICAL 2, has the highest level of coffee production among all farmers and is the only agroecological farmer who did not have a good performance in the final ranking, with low values using the WPM and TOPSIS methods. This result means that crop production is a residual element of the total value when other dimensions of sustainability are considered. The same farmer (AGROECOLOGICAL 2) has high levels of variation in income generation in different coffee price scenarios and a high dependency on coffee production. This result leads to a very low level of resilience in the presence of a coffee price decrease, which is quite usual in internationally traded crop markets, especially for coffee (cf., ICO, 2011). The volatility of income was measured as the standard deviation (SD) of the three scenarios of income generation with different price assumptions (see the Supplementary Material, Section Dimensions, equation (2)) that farmer had the highest value within the sample, suggesting high instability in income generation.

AGROECOLOGICAL 4 and AGROECOLOGICAL 5 are the best performers in the rankings because of their high level of diversification of crop production for generating income, low levels of chemicals and low level of labor intensity because agroecological systems reduce the need for human control of their production activities. In the case of AGROECOLOGICAL 5, this farmer's coffee production is one of the highest in the sample because of the use of agroecological methods and production diversification.

Conventional farmers are mainly ranked at the bottom part of the ranking, but some of them (e.g., CONVENTIONAL 1, CONVENTIONAL 5 and CONVENTIONAL LARGE) perform better than some agroecological farmers (i.e., AGROECOLOGICAL 3 and AGROECOLOGICAL 2 for WSM, AGROECOLOGICAL 2 for WPM). On average, conventional farmers have weaknesses in social and environmental dimensions, whereas they perform well in the economic dimension. Conventional farmers also show levels of production above the mean, but their profit margin is mainly eroded by the high costs of conventional methods based on the high application of chemicals and work for crop control activities. These classifications are well defined using the TOPSIS method, which describes the distance from the ideal and nadir farms within the sample, indicating that conventional farmers always have lower systemic sustainability than agroecological farmers (Table 2 last column).

Discussion

The results of this study suggest the potential of agroecology to boost sustainable development in the East region of MG. Analysis of the results is based on a specific case study, but the area has many similarities with other rural areas in Latin America regarding all the dimensions of sustainability considered (economic, social and environmental).

Our results show that agroecological farms, even with their lower levels of coffee productivity on average, have better income stabilization. This result depends on product diversification (such as agri-food products, vegetables or fruits) for local markets, which reduces the risk of farmers associated with coffee price volatility, improving both the local economy and local food security. Moreover, as agroecological farms rely more on labor than capital, their diffusion could improve local employment conditions, reducing migrations toward large cities and shanty towns in other parts of Brazil. Considering the environmental dimension, agroecological farms support agrobiodiversity, reduce agricultural pollution (in the water table and soil by not using chemical inputs) and improve forest conservation as trees are used to increase the potential resilience of the agroecosystem.

In general, empirical works on sustainability assessment of agroecology are still limited, and the results of this study confirm the positive effects of agroecology and encourage sustainable and fair development of agroecology in rural areas of developing countries to improve socio-economic conditions and conserving the environment at the same time (Garibaldi *et al*., 2016; D'Annolfo *et al*., 2017). In fact, agroecology can support the sustainable development of rural areas that have a structure and operation of small farming similar to the area and sample under study here. Transition toward agroecology in the region could be achieved through policies supporting the implementation of sustainable practices with high positive externalities in all dimensions of sustainability (such as economic and environmental improvements) and the low negative externalities associated with conventional coffee production, such as price volatility risks, rural poverty and environmental problems caused by monoculture production. Agroecology is an appropriate approach for small farming and is adaptable to local conditions, focusing on labor and knowledge rather than capital and financial assets.

We know that the agroecological systems adopted in the area are only a small portion of the total farms, but in the evolution of agroecology, these small farmers represent the first adopters of an organized innovation process for the wide diffusion of agroecology at a larger scale. Although the overall effects on the regional ecosystem and socio-economic structure are low, the positive effect in terms of improving farm economic conditions can encourage other coffee farmers to transform their farm system with more agroecological practices. Nevertheless, farmers may be reluctant to change their organization toward agroecological practices until they do not perceive substantial income improvements through the use of new technology (Rodriguez *et al*., 2009; Cavallo *et al*., 2014, 2015; Coccia, 2019; Coccia and Watts, 2020). Therefore, the positive performance of agroecological farmers in terms of social and economic aspects could stimulate others to pursue a similar approach in converting their practices. At the local level, municipalities or regional development agencies could stimulate an agroecological transition through providing direct monetary incentives, organizing events, and holding courses for cross-fertilization of knowledge among farmers using agroecology (Altieri and Rosset, 1996). The main example is the 'campesino a campesino' program adopted in the last few decades in Latin America (Rosset *et al*., 2011). In addition, rural development agencies could operate indirectly, encouraging the use of agroecological certifications to diversify agroecological products and stimulate other farmers to convert their productions (Warner, 2006).

Conclusion and limitations

This study applies a holistic and systemic approach to evaluate sustainability in coffee production for small farming, and the results reveal that agroecology definitively performs better than conventional practices in terms of single and manifold dimensions of sustainability. Although the main purpose of the study was not to perform a regional case study, this study carried out a comparative analysis of two different systems of coffee production, and the limitations of this study are related to the small sample under study, which reduces the generalizability of the results. Anyway, the application of small samples is often present with MCA (Munda *et al*., 1994) and other studies on rural development (see Bockstaller *et al*., 1997; Lopez-Ridaura *et al*., 2002; Chaparro Africano and Collado, 2017). In addition, our data source was based on direct interviews with farmers, and although the information was controlled and validated by local experts, it could be biased. This issue is difficult to overcome and is common in other similar studies in this and other fields of research (Di Cicco-Bloom and Crabtree, 2006).

To conclude, agroecology supports the sustainable development of the East MG region, but these conclusions are tentative. There is a need for a much more detailed research to perform a comparative analysis between agroecological and conventional agricultural systems, using, whenever possible, larger samples and other regions of Brazil to achieve higher statistical robustness and additional quantitative evidence to suggest the appropriate best practices of regional and national policies.

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