AP AGRO PRODUCTIVIDAD

Colegio de Postgraduados

Bibliographic analysis of sustainability studies in coffee agroecosystem from 2010 to 2019

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ABSTRACT

Phytosanitary problems and low prices have put coffee production in a critical situation, affecting the economy of producers and the area cultivated with coffee in the state of Veracruz. The objective of this work was to carry out a systematic review of the main researches carried out on sustainability in the coffee agroecosystem and reported in the scientific literature of the last ten years.

The methodology applied was documentary in nature and it was based on the bibliographic review in the search engines Google Scholar, Scopus, and Elsevier Science Direct Freedom. The English and Spanish "evaluation", "sustainability", and "coffee" concepts were input into the search engines, combined with Boolean operators. In the last ten years, sustainability studies about coffee agroecosystems were published in South America (Colombia, Peru, Ecuador, and Brazil) and Africa (Uganda) analyzing economic, social, and environmental dimensions. With regard to the evaluation methods, 35.71% used sustainability indexes, performing comparisons between agroecosystems, and endeavored to monitor trends. The Framework for the Evaluation of Natural Resource Management Systems Incorporating Sustainability Indicators (MESMIS) supported 28.57% of the methods. The rest of the studies (7.14%) proposed methodologies that have been validated and adapted to the object-context and the objective. In addition, it was identified that the analysis of the sustainability of the coffee agroecosystem is not close related to the type of coffee system (conventional, organic or agroecological), since the interactions that occur within each system are diverse and complex; social or cultural perceptions are factors that reduce or promote the search for sustainability. It is concluded that few studies (14) about sustainability of coffee agroecosystems have been published during 2010-2019 period.

Keywords: Evaluation, sustainability, coffee plantation, literature review, analysis.

Citation: Pérez-Sánchez, O., Pérez-Vázquez, A., Lango-Reynoso, V., Gallardo-López, F., & Escamilla-Prado, E. (2022). Bibliographic analysis of sustainability studies in coffee agroecosystem from 2010 to 2019. *Agro Productividad*. https://doi.org/10.32854/agrop.v15i3.2129

Editor in Chief: Dr. Jorge Cadena Iñiguez

Received: September 20, 2021.
Accepted: February 18, 2022.
Published on-line: April 5, 2022.

Agro Productividad, 15(3). March. 2022. pp: 61-73.

INTRODUCTION

Coffee (*Coffea arabica* L.) is one of the most important crops worldwide. It is particularly important in Latin America, as a consequence of its contribution to foreign exchange, based on the sale of grain in the international market (Canet *et al.*, 2016). A shade-grown coffee plantation is a sustainable agroecosystem at several levels: a the environment level, it is considered environmentally friendly, for its contribution to biodiversity conservation (Greenberg *et al.*, 1997; Cruz-Lara *et al.*, 2004; Rivera and Armbrecht, 2005; Macip-Ríos and Casas-Andreu, 2008); at social level, for its contribution to the rural livelihoods of

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farmers (Kimaro *et al.*, 2017); and, at the economic level, as a result of the income and job creation from the sale of grain (Figueroa *et al.*, 2015). Likewise, it directly or indirectly provides environmental services to society, if it is carried out under sustainable management practices (Tinoco, 2010). However, various and serious phytosanitary problems (leaf rust, borer, etc.) that impact coffee have been reflected in a loss of plants and low fruit yields and quality, coupled with the volatility of international prices and coffee crisis (Rizzuto and Rosales, 2014).

Faced with this situation, producers have ventured into alternative coffee production agroecosystems —some of them with less plant diversity or directly exposed to sunlight under an intensive agricultural management and single-crop system—, in order to increase yield and profitability per hectare (Meyfroidt *et al.*, 2014; Perfecto and Vandermeer, 2015). This change has generated several negative externalities and agroecosystems with a high negative environmental impact. Small coffee producers are the most affected by the volatility of the price of coffee in the international market, since the economic and government policies of each country have a direct impact on the management of such agroecosystem (Batz and Blackman, 2010). Therefore, producers are facing up with the dilemma of producing more at the cost of losing biodiversity and operating the ecosystem services provided by coffee plantations under traditional management (Moguel and Toledo, 1999).

Several researchers worldwide have recently taken on the task of assessing the sustainability aspects of the coffee agroecosystem. Some of these studies use methodologies such as the Framework for the Evaluation of Natural Resource Management Systems Incorporating Sustainability Indicators (MESMIS) (Masera and Astier, 1999; López-Ridaura, 2000) or the evaluation framework by hierarchy of levels (dimension-category-indicator) proposed by Sarandón and Flores (2009). Although sustainability is certainly an approach present in various human activities and in multiple studies (Speelman *et al.*, 2007; Manzon *et al.*, 2008; Castro-Tanzi *et al.*, 2012; Robert *et al.*, 2019; De Muner, 2019), the search for sustainability is also something that society aims and aspires to, as well as a proposal made by many government institutions, particularly those focused on agricultural activities and those focused on human, social, and economic development, as well as on the conservation of natural resources (Candelaria *et al.*, 2014, López-Santos, 2016).

The concept of sustainability has had several definitions, from the original definition coined in the Bruntland Report (1982) to more specific and innovative ones in which its economic, political, ecological, environmental, and social dimensions are included as central axes. In this regard, Corrales (2001) mentions that sustainability in the agricultural field refers to the restoration capacity of the renewable natural resources used for agricultural production and to other productions inputs. Likewise, Mac Rae *et al.* (1989) pointed out that sustainable agriculture includes management procedures that work with processes to preserve all resources, minimize waste and environmental impact, prevent problems, and promote resilience, self-regulation, evolution, and sustainability of agroecosystems for the well-being of all. Understanding what sustainability is or should be varies according to each discipline and field. Therefore, there will be discrepancies between the concepts of sustainability, on the one hand, and agriculture and sustainable development, on the other.

Considering that no bibliometric studies on coffee sustainability issues were identified, the aim of this paper was to document, through a systematic review, the various sustainability studies carried out during the last ten years about the coffee agroecosystem in different regions of the world. The purpose of this study was to identify their characteristics and recognize the sustainability methodologies used and their main contribution to the field.

MATERIALS AND METHODS

A search of published literature on sustainability studies in the coffee agroecosystem was carried out from January 2019 to December 2020. Documentary sources such as Scopus, Elsevier Science Direct Freedom, and Google Scholar were used. In the advanced search section, fundamental concepts such as "assessment", "sustainability", and "coffee" were used for search engines in English and "evaluación", "sustentabilidad", and "café" for databases in Spanish.

Inclusion and exclusion criteria

Scientific articles from the last 10 years (2010-2019) were included, selecting studies related to sustainability assessments in coffee agroecosystems worldwide. The relevant information of each publication was extracted and tabulated for analysis. The study sites mentioned in the publications were georeferenced to generate a map and visualize the spatial distribution of knowledge about sustainability in the coffee agroecosystem.

The information collected was captured and processed in an Excel spreadsheet. To facilitate the analysis, the following variables were determined: location, evaluation method, type of study, objective, scale and type of producer, systems evaluated, areas of sustainability evaluation, and type of study carried out (cross-sectional or longitudinal). The quotes were processed using the EndNote bibliographic reference manager software. The information is presented as tables, figures, and charts.

RESULTS AND DISCUSSION

Bibliometric analysis is a methodology that helps to determine recent trends in publications on a specific topic, finding related topics, regardless of the amount of research that has been carried out or even if there are knowledge gaps. The implementation of the search protocol through the defined routes showed that 15,800 articles had been published in the period researched (2010-2019). In view of the high number, the pre-established (inclusion and exclusion) criteria were applied. Later the first 100 were analyzed, discarding those that were not related with a sustainability evaluation in the coffee agroecosystem. The Scopus search engine returned 38 documents. However, all duplicate references were discarded, as well as articles that did not make a significant contribution to the topic of sustainability. The Elsevier Science Direct Freedom search engine returned 43 articles and the same procedure was applied. Finally, after carrying out a full text review of each article and, bearing in mind the previous restrictions, the search for information continued to be refined until a total of 12 articles from Google Scholar, 1 from Scopus, and 1 from Elsevier were left.

Coffee agroecosystems (conventional, organic, and agroecological)

The various typologies of the coffee agroecosystems analyzed differ in terms of shade characteristics (structure and functioning), biodiversity, and technology applied to agronomic management. These agroecosystems include mountain, traditional polyculture, commercial polyculture, specialized, and full sun (Moguel and Toledo, 1999; Escamilla and Díaz, 2016). This differentiation responds to a strategy aimed at generating higher income particularly induced by the international grain price crisis, as well as by the presence and recurrence of pests and diseases. Some differentiated management agroecosystems also respond to the agroecological condition and the regional, social, political, and economic context of each country. In this regard, Altieri (1994) and Sarandón (2002) mention that technologies, whether they are similar or different, can be promoted as sustainable technologies, as long as there is no benchmark for comparison (Figure 1). The possibility of a comparative study of agronomic management in coffee agroecosystems arises at this point. Sarandón (2002) proposes to measure sustainability through an index that allows determining which of the agronomic management technologies provides a greater or lesser sustainability to the system.

Merma and Julca (2012) mention that in Cusco, Peru, the prevailing crops are coffee, cocoa, tea, coca, and tropical fruit trees for sale, along with annual crops and breeding for self-consumption. Figueroa-Lucero (2016) points out that conventional farms in Linares-Nariño, Colombia, are linked to households and they are surrounded by coffee plots where other systems coexist: fruit trees, vegetable patch, fish farming, and the fauna present in the trees. In the case of Ecuador, Méndez *et al.* (2017) mention that the production obtained in most of the coffee farms is for self-consumption.

Other coffee farms choose to provide tourist services, like in Quindío, Colombia, where the farms function as rural agro-ecotourism business units (Rincón et al., 2015), taking advantage of what is known as birdwatching tourism under the scheme of multifunctional agriculture (Maldonado *et al.*, 2018). Organic coffee agroecosystems are typical of Peru, Ecuador, Nicaragua, El Salvador, Guatemala, and Mexico (Perea, 2010). Cárdenas-Grajales and Acevedo-Osorio (2015) describe the organic coffee system in Valle del Cauca in Colombia, as productive systems where producers are organized and have an

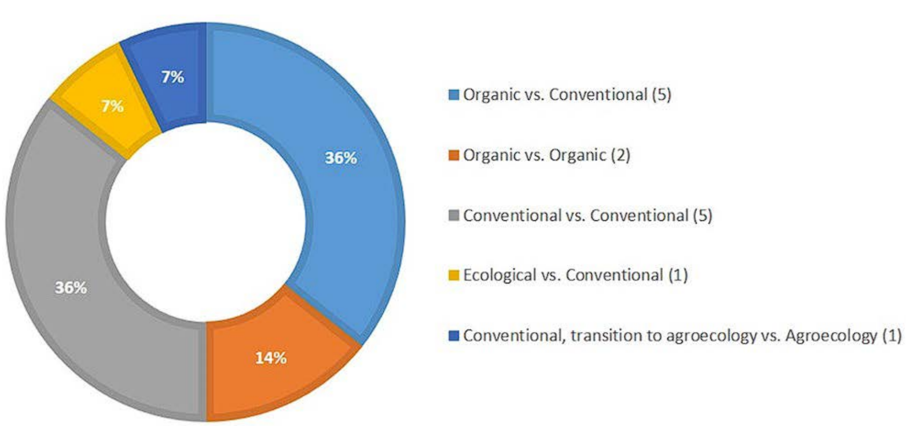


Figure 1. Coffee systems evaluated in terms of global sustainability (2010-2019 period).

average area of 1-10 hectares with predominance of coffee. The workforce is mostly based on family members, income comes almost exclusively from the farm, and part of the production is used for self-consumption. The main source of income comes from the sale of organic coffee and, on a smaller scale, from the marketing of bananas and other fruits. Guevara and Vázquez (2019) point out that 100% of the coffee production in the Peruvian Amazonia is organic, with cultivation systems with little association and diversification of crops; additionally, there is a high dependence on coffee cultivation. For their part, León and Delgado (2012) describe four types of farms in Caldas, Colombia: 1) organic coffee-growing households, 2) farmer coffee-growing households, 3) non-land-owning managers and sharecropers households, and 4) farmer coffee-growing households with entrepreneurial tendency.

Meanwhile, Alvarado (2013) reports a comparison between conventional coffee and organic coffee in Peru. Márquez-Romero *et al.* (2016) compared a conventional production system and an organic production system in Manabí Ecuador, during a seven-year period on the same farm. Another comparative evaluation of organic versus conventional systems was carried out by Ssebunya *et al.* (2019) in western Uganda, where 90% of the coffee comes from small producers of Robusta (*Coffea canephora*) and Arabica (*Coffea arabica*) coffee. In Uganda, coffee is often intercropped with bananas, annual crops or shade trees. Although 100% of the production in Bushenyi and Kasese is organic, their farming system contains little association and diversification of crops and is, therefore, highly dependent on coffee cultivation.

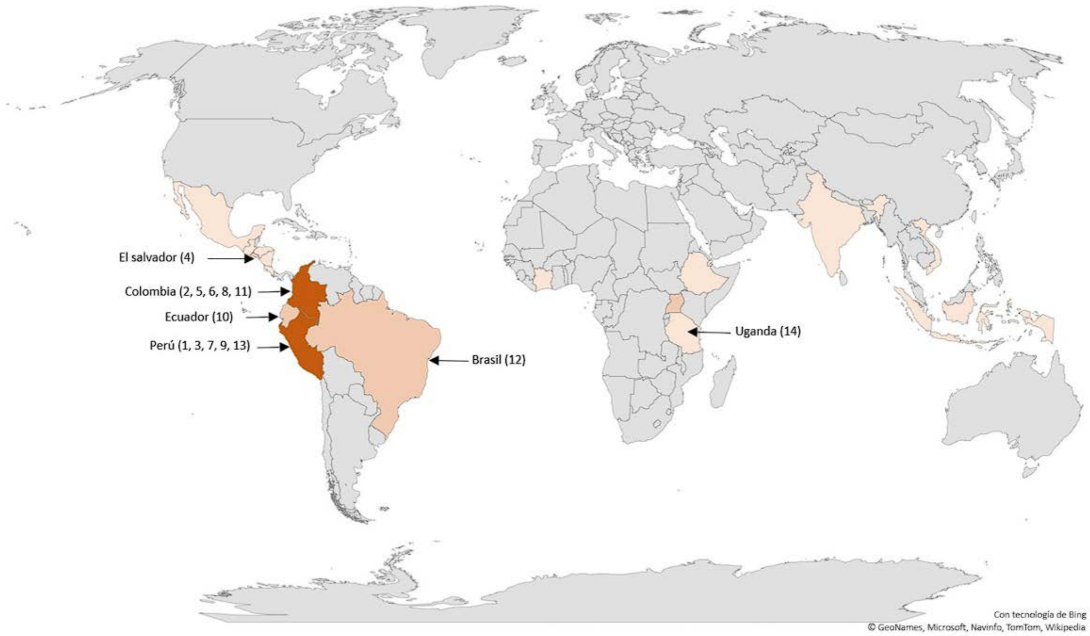
Countries with sustainability studies in the coffee agroecosystem

According to the International Coffee Organization (ICO, 2020), the main coffee producing countries are: Brazil, Vietnam, Colombia, Indonesia, Honduras, Ethiopia, India, Uganda, Mexico, and Peru. Nevertheless, the literature indicates that, over the course of the last ten years, sustainability studies have been carried out only in South America (Colombia, Peru, Ecuador, and Brazil) and in Africa (Uganda) (Figure 2). These studies have taken into consideration agroecological indicators or the different modalities of the coffee production system. They have been compared based on the multidimensional variables that come together at the social, economic, and environmental edges.

Evaluation methods

The outstanding proposal made by Sarandón *et al.* (2009) accounts for 35.71% of the methodologies used and is comprised of five researches (Merma and Julca, 2012; Márquez and Julca, 2015; Márquez-Romero *et al.*, 2016; Méndez *et al.*, 2017; Guevara and Vázquez, 2019). This method is based on the application of a qualitative approach; it uses indicators and is based on comparisons between agroecosystems; it monitors progress on a time scale with regard to the greater or lower sustainability during the transition process (Sarandón and Flores 2009) (Figure 3).

The other method used to assess the sustainability of coffee agroecosystems is the Framework for the Evaluation of Natural Resource Management Systems Incorporating



	Año		Año		Año
1. Merma y Julca	2012	**6.** Rincón *et al.*	2015	**11.** Rendón y Monroy	2017
2. León y Delgado	2012	**7.** Márquez y Julca	2015	**12.** De Muner	2019
3. Alvarado	2013	**8.** Figueroa-Lucero	2016	**13.** Guevara y Vásquez	2019
4. Cárdenas-Grajales y Acevedo-Osorio	2015	**9.** Márquez-Romero *et al.*	2016	**14.** Ssebunya *et al.*	2019
5. Giraldo-Díaz *et al.*	2015	**10.** Méndez *et al.*	2017		

Figure 2. Countries that have evaluated the sustainability of the coffee agroecosystem. Period: 2010-2019.

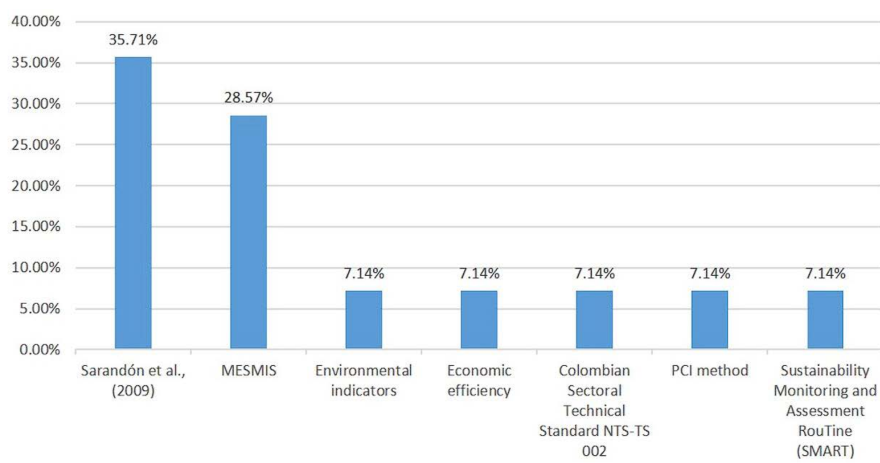


Figure 3. Sustainability evaluation methods in the coffee agroecosystem. Period: 2010-2019.

Sustainability Indicators (MESMIS), with a 28.57% representation, which is based on the analysis of attributes such as productivity, resilience, reliability, and stability in a comparative context. This method has been applied in four coffee researches (Cárdenas-Grajales and Acevedo-Osorio, 2015; Giraldo-Díaz, 2015; Rendón and Monroy, 2017; De Muner, 2019). The rest of the researches (7.14% each) employed methods based on the use of environmental indicators (Altieri and Nicholls, 2002), as well as the measurement of economic efficiency with the Stochastic Frontier Analysis (Alvarado, 2013). In Colombia, sustainability indicators have been based on the Norma Técnica NTS-TS Sectorial Colombiana 002, which promotes the sustainable development of tourism and is part of the country's ten-year strategic plan (Rincón *et al.*, 2015). In another study conducted in Colombia, the PCI method was used (Figueroa-Lucero, 2016).

In Uganda, researchers have applied the Sustainability Assessment of the Food and Agriculture systems (SAFA) (FAO, 2014), which served as the basis for the development of a multi-criteria, indicator-based assessment tool, known as the Sustainability Monitoring and Assessment Routine (SMART) - Farm Tool (Schader *et al.*, 2016). Other researchers, including Pronti and Coccia (2021), have used a multi-criteria methodology to assess the sustainability performance of agroecological and conventional coffee. For their part, Palestina-González *et al.* (2021) recently used a sustainability index to evaluate a traditional coffee agroecosystem. This tool brings together a set of indicators to support the comparative and synergy analysis created by the Research Institute of Organic Agriculture. This matches the findings of Rodríguez and López (2007) and Kú *et al.* (2013) about the existence of various sustainability assessment methods, among which evaluation frameworks, multi-criteria methods, and sustainability indexes stand out; the most accepted methods are those that make use of a multi-dimensional approach (Table 1).

Table 1. Agroecosystems evaluated, location, and methods used to evaluate sustainability.

Reference	Agroecosystems studied	Ubication	Assessment method
Merma and Julca (2012)	Conventional *vs.* Conventional	Cusco, Perú	Sarandón (2002)
León and Delgado (2012)	Organic *vs.* Conventional	Caldas, Colombia	Altieri y Nicholls (2002)
Alvarado (2013)	Organic *vs.* Conventional	Piura, Perú	Economic efficiency (Frontera estocástica)
Cárdenas-Grajales and Acevedo-Osorio (2015)	Organic *vs.* Conventional	Valle de Cauca, Colombia	MESMIS and participative approach
Giraldo-Díaz *et al.* (2015)	Conventional, transition to agroecology *vs.* agroecológical	Valle de Cauca, Colombia	MESMIS and participative approach
Rincón *et al.* (2015)	Conventional *vs.* Conventional	Quindío, Colombia	Technical norm Colombian sectorial technique
Márquez and Julca (2015)	Conventional *vs.* Conventional	Cusco, Perú	Adaptation of Sarandón *et al.* (2006)
Figueroa-Lucero (2016)	Conventional and Organic	Linares-Nariño, Colombia	PCI
Márquez-Romero *et al.* (2016)	Organic vs Organic	Cusco, Perú	Sarandón y Flores (2009)
Méndez *et al.* (2017)	Conventional *vs.* Conventional	Manabí, Ecuador	Sarandón *et al.* (2004)
Rendón and Monroy (2017)	Conventional *vs.* Conventional	Cauca y Caquetá, Colombia	MESMIS
De Muner (2019)	Ecological *vs.* Conventional	Espíritu Santo, Brasil	MESMIS and participative approach
Guevara and Vázquez (2019)	Organic *vs.* Organic	Amazonas, Perú	Sarandón (2002)
Ssebunya *et al.* (2019)	Organic *vs.* Conventional	Bushenyi y Kasense, Uganda	Sustainability Monitoring and Assessment RouTine (SMART) (Schader *et al.*, 2016)

Type of study

Another noteworthy aspect is the eleven cross-sectional studies that were carried out (Table 2). In other words, one or more alternative or innovative management systems has been simultaneously compared with a reference system or with each other (Masera *et al.*, 1999; López-Ridaura *et al.*, 2002). Only two longitudinal studies were carried out, comparing the same system over time. This limited number, may be caused by the difficulty of obtaining historical series, as well as of capturing the dynamic aspects of management systems (Martínez-Castro *et al.*, 2015). The diverse evaluation scales were used to analyze the regional, municipal, community, production system, production unit, and farm levels (Table 2). The researches were carried out during the 2012-2019 period.

Sustainability concept

The discrepancies in the definition of sustainability are reflected through the construction and application of its indicators, which are mostly site-context. Simón (2003) mentions that the results vary depending on the approach, the evolution of the debate about the definition of sustainability, and the construction of indicators. In addition, no agreement has been reached about what should or could be the best indicator of sustainability, because there are no fixed or exact definitions of the concept, since they are site-context dependent.

Conceptualizing the term "sustainability" before starting an evaluation of the coffee agroecosystem is relevant, because this concept will indicate the approach, as well as the factors or dimensions involved in the evaluation, delimiting the spatial and temporal scale of the research. However, the said studies do not always include the definition of the term sustainability, on which they should have been based. However, there is a consensus among the researches that do define the concept: the term is based on maintaining, preserving, and keeping the system functional (Table 3). Sustainability also implies maintaining a

Table 2. Type of scale, evaluation area(s), type of research.

Reference	Level of hierarchy	Dimensions of assessment	Type of study
Merma and Julca (2012)	Region	Economic, ecology and cultural	Transversal
León and Delgado (2012)	Municipal	Economic, ecology and social	Transversal
Alvarado (2013)	Region	Economic and environmental	Transversal
Cárdenas-Grajales and Acevedo-Osorio (2015)	Production system	Economic, ecology, sociocultural and tecnoproductive	Longitudinal
Giraldo-Díaz *et al.* (2015)	Production system	Economic, ecology, cultural, social and political	Transversal
Rincón *et al.* (2015)	Unit of production	Economic, ecology and sociocultural	Transversal
Márquez and Julca (2015)	Farm	Economic, ecology and sociocultural	Transversal
Figueroa-Lucero (2016)	Farm	Economic, ecology, social, cultural, and political	Transversal
Márquez-Romero *et al.* (2016)	Farm	Ecological	Longitudinal
Méndez *et al.* (2017)	Community	Economic, ecology and sociocultural	Transversal
Rendón and Monroy (2017)	Municipal	Economic, ecology and cultural	Transversal
De Muner (2017)	Unit of production	Economic, ecology and social	Transversal
Guevara and Vázquez (2019)	Community	Economic, ecology and sociocultural	Transversal
Ssebunya *et al.* (2019)	Production system	Economic, environmental, social and gobernance	Transversal

certain defined and acceptable level of food, fuel, and/or fiber production and raising the quality of life over time (along with the human, social, and economic well-being), as well as preserving natural resources and the environment on a certain functional spatial and temporal scale.

Which coffee production system is more sustainable?

Merma and Julca (2012) point out that conventional coffee, cocoa, and fruit farms in Cusco, Peru, have higher sustainability rates than tea and coca farms. The opposite was the case in Manabí, Ecuador, where 93.9% of conventional farms had a Índice de Sustentabilidad General (IS Gen) <2 (on a scale of 0 to 5), indicating that most of the

Table 3. Concepts and approaches with which sustainability has been addressed in the coffee agroecosystem.

Reference	Concept	Approach
Merma y Julca (2012)	Sustainability is defined as the ability of a system to maintain productivity even when if it is under "stress or disturbances"." (Conway, 1994).	Economic, ecological, and cultural
León and Delgado (2012)	Sustainability refers to the permanence of the production systems, their ability to be maintained over time. Gives an idea of maintaining the productivity of the natural resources, under situations of shock or tension.	Economic, environment y social
Alvarado (2013)	Sustainability implies managing resources in such a way that their long-term abundance and quality is assured for future generations.	Economic and environmental
Cárdenas-Grajales and Acevedo-Osorio (2015)	Without concept	Economic, ecological, sociocultural, and techno-productive
Giraldo-Díaz *et al.* (2015)	Without concept	Economic, ecological, cultural, social, and political
Rincón *et al.* (2015)	Sustainable is the system that best fit to the capacity for autonomy, and the capacity of the system to use self-management to generate the necessary income, preserving natural resources.	Economic, ecological, and sociocultural
Márquez and Julca (2015)	Sustainability is a complex concept that aims to meet several objectives simultaneously, involving productive, ecological, social, cultural, economic dimensions on time scale (Sarandón, 2002)	Economic, environmental, and sociocultural
Figueroa-Lucero (2016)	Sustainability is the "ability to create, test, and maintain adaptive capacity" (Holling, 2002 in Bermejo, 2005: 44pp),	Economic, environment, social, cultural, and political
Márquez-Romero *et al.* (2016)	Living within the productive capacity of the planet	Ecological
Méndez *et al.* (2017)	Sustainable agriculture as one that promotes food sufficiency, conserves natural resources, protects the environment and is economically viable (Gómez-Limón *et al.*, 2011)	Economic, ecological, and sociocultural
Rendón and Monroy (2017)	Without concept	Economic, ecological, and cultural
De Muner (2019)	Without concept	Economic, environmental, and social
Guevara and Vázquez (2019)	Sustainability is a development that meets the needs of present generations without compromising the ability of future generations to meet their own needs. (Daly, 2002).	Economic, ecological, and sociocultural
Ssebunya *et al.* (2019)	Without concept	Economic, environmental, social and gobernance

farms were not sustainable (Méndez *et al.*, 2017). Meanwhile, Rendón and Monroy (2017) indicate that, in Colombia, the results conclude that the coffee ecosystems of Ufugú (Cauca) are potentially sustainable in the social and ecological spheres, and actually sustainable in the economic sphere. On their part, the agroecosystems of Sucre (Caquetá) are potentially sustainable in the ecological sphere, and moderately sustainable in the social and economic spheres. These results are the consequence of a high level of support for farmer families which have certifications such as the Rainforest Alliance; this type of certificates helps to increase the profitability of the producer and improves cost and benefit of the crop (Rendón and Monroy, 2017).

A study carried out in Quindío, Colombia showed a general interest in the environmental management of coffee units with tourist activity (Rincón *et al.*, 2015). Another case reported in the same country registers a general sustainability average of 3.2 (on a scale of 1 to 5) and is therefore sufficient for the sustainability of the conventional coffee agroecosystem (Figueroa-Lucero, 2016). Meanwhile the organic farms in Caldas, Colombia, have better soil quality than conventional coffee production farms. This group presents higher soil quality averages (8.1, on a scale of 1 to 10), because their soils are better managed than the soils of conventional farms, whose averages are lower than 8.0 (León and Delgado, 2012). Similarly, Alvarado (2013) mentions that the net income or benefits of organic producers in Piura, Peru, are higher than those of conventional producers in the four scenarios considered, in which the nutrient balance costs are lower than for organic production. This confirms that this type of production is more sustainable than conventional production. The study carried out in organic farms of Valle del Cauca, Colombia, shows that the sustainability of organic coffee systems had a balanced behavior during the five years of evaluation (Cárdenas-Grajales and Acevedo-Osorio). In a comparative study between certified and non-certified organic farms in Uganda, the scores of certified farms were significantly higher than non-certified farms; this is attributed to the fact that *C. arabica* producers carry out more collective activities (distribution of labor, saving plans) which have repercussions on the other dimensions (Ssebunya *et al.*, 2019).

The foregoing highlights the positive impacts of certification on the livelihoods of small coffee producers; certifications make a significant contribution to the improvement of systems and the ability of farmers to face challenges, through the transfer of knowledge, access to capital, capacity-building (Altenbuchner *et al.*, 2014), and higher income generation (Bolwig *et al.*, 2009; Chiputwa *et al.*, 2015). Meanwhile, Márquez-Romero (2016) reached similar conclusions: the organic certification process enabled the increase of the number of sustainable farms, from 66.6% to 91.1%. Similarly, productivity increased (from 665.16 to 858.38 kg/ha) and grain quality improved (from 80.64 to 82.56 points) after seven years.

Although certifications certainly promote sustainability, it also depends, to a large extent, on decision-makers, as is the case of farms with agroecological management in Brazil, where a lower dependence on synthetic inputs for coffee cultivation, less use of technology, and more ecological management were recorded, compared to farms with conventional management (De Muner, 2019). A similar case is that of Valle del Cauca (Colombia), where producers depend largely on products for self-consumption and selfemployment. However, the economic profitability is limited, in many cases, by the lack of spaces for the commercialization of agroecological products (Giraldo-Díaz *et al*., 2015), putting the sustainability of the system at risk.

CONCLUSIONS

During the last ten years, the trend in sustainability research regarding coffee agroecosystems in the scientific literature shows that there have been few studies about this topic. The most sustainable agroecosystems are those that have some type of certification and where the producers are organized or have government support. Unsustainable coffee agroecosystems are those that do not have an extension service, do not implement agroecological practices, do not preserve the soil, and do not have access to financing to renew coffee plantations; additionally, they lack the technical support and economic benefits to which organized producers have access to. Regarding the mostly-downwards fluctuation of prices, coffee producers have established strategies to supplement their income and remain in the activity, even if it is not enough to cover family needs. Finally, the sustainability of the coffee agroecosystem is not merely related to the type of agroecosystem (conventional, organic, traditional, etc.), but depends on prices, support, and the incidence of climatological and biological factors: there are many sustainable conventional coffee plantations and non-sustainable agroecological plantations. The interactions that occur within each type of agroecosystem are diverse and complex. Therefore, further longitudinal, and cross-sectional sustainability studies are necessary to contribute to the identification of the factors that provide greater sustainability to the various coffee agroecosystems. Likewise, it is essential that sustainability assessment have continuity on a larger time scale and on spatial scales, taking in consideration the dynamic dimensions as a whole.

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