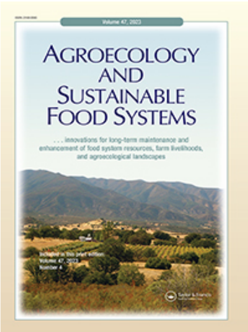


Taylor & Francis
Taylor & Francis Group

Agroecology and Sustainable Food Systems

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/wjsa21

The need for a unified agroecosystem concept

Velez Leon Dario & Muriel Sandra B

To cite this article: Velez Leon Dario & Muriel Sandra B (2023) The need for a unified agroecosystem concept, Agroecology and Sustainable Food Systems, 47:4, 621-640, DOI: 10.1080/21683565.2023.2169431

To link to this article: https://doi.org/10.1080/21683565.2023.2169431

AGROECOLOGY AND SUSTAINABLE FOOD SYSTEMS
2023, VOL. 47, NO. 4, 621–640
https://doi.org/10.1080/21683565.2023.2169431

Taylor & Francis
Taylor & Francis Group

Check for updates

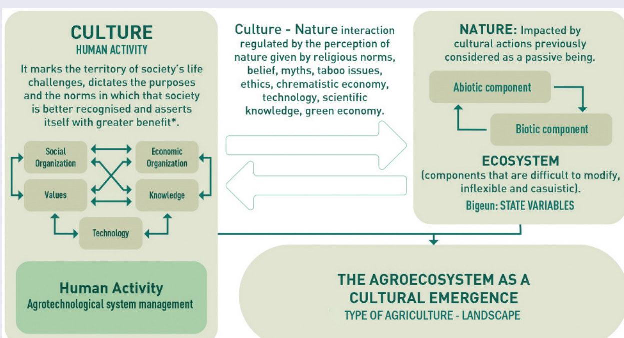
The need for a unified agroecosystem concept

Velez Leon Dario [a] and Muriel Sandra B [b]

[a]Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, Medellín, Colombia; [b]Facultad de Ciencias Agrarias, Politécnico Colombiano Jaime Isaza Cadavid, Medellín, Colombia

ABSTRACT

Typically, the agroecosystem is known as the basic unit of study of the agroecology. However, no consensus exists regarding its definition, which is reflected by the early state of agroecology as a science. This fact was illustrated after an exhaustive analytical review of the different agroecosystem definitions proposed and currently used in the literature. We reviewed 157 articles and other key scientific literature and found seven different concepts. It is necessary to advance in unification of the terminology to bridge the gaps among agroecology, agricultural sciences, and other disciplines that enable progress toward sustainable agriculture. Therefore, the objective of the present study was to propose a discussion about the need to have a semantic and operational concept of agroecosystem. Agroecosystem is a synthesis, product of the culture – nature interaction, it is regarded as a homogeneous natural unit, where an agrotechnological management system (AMS) is introduced according to farmer needs. Therefore, the agroecosystem is a holistic, irreducible, and particular basic unit of agroecology and the agricultural sciences, which integrates production processes and attributes for a sustainable agriculture.



KEYWORDS
Agroecology; agroecosystem; agriculture; system; sustainability; epistemology

Introduction

When referring to the election of a basic unit in ecology, Holdridge (2009) stated the following: *"One of the major problems in any science is that of determining the basic natural units with which one must work. The biological*

CONTACT Velez Leon Dario ldvelez@unal.edu.co Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, Calle 65 #59A-110, Medellín, Colombia
Supplemental data for this article can be accessed online at https://doi.org/10.1080/21683565.2023.2169431

sciences could not develop far until the invention of the microscope, with which the cell was found to be the basic building block of animal and plant life. Chemistry made rapid advances as soon as a correct identification of the elements was initiated . . . if the basic unit has been properly chosen, continued study brings about a general agreement as to the correct definition of each unit . . . "

Agroecosystem has been defined as a dynamic and spatial basic unit in the agroecology (Altieri 1999; Hernández 1999), and, in some cases, of the agricultural sciences (in Spanish: Facultad de Ciencias Agrarias [undefined). However, despite the current agreement related to its importance, the reviewed literature does not account for a unique and accurate concept of agroecosystem from a scientific standpoint, i.e., focusing on a formal logic, the epistemology and the praxis (Alpa 1994; Ferrater-Mora ; Flores 2011; Honderich and Trevijano 2008; Prigogine and Stengers 1990; Putnam 1984; Tamayo 2011).

Altieri (1999), Gliessman et al. (2007) and León, Mendoza, and Córdoba (2014) state that the agroecosystem can be defined in several ways, in addition to the challenges experienced establishing an accurate limitation and defining the best unit of analysis. A unique and unambiguous concept of agroecosystem is required to constitute the basic unit of reference in terms of the following: assessment of production processes; knowledge generation and technology creation; and social, ecological, technological, economic and cultural performance indicators. This will help account for both the vulnerability and sustainability of the agroecosystems, to comparatively analyze agroecosystems and to build logical, clear and non-redundant taxonomy and hierarchy that complete the theoretical body of agroecology as a scientific discipline. León (2014) stated that this a crucial matter involving the definition of a minimum unit to shed different lights on taxonomic, functional, applied, knowledge transfer and technology-related matters and as a factual reference for social relations and formulation of public policies.

On the basis of previous considerations, the problem can be addressed by constructing and selecting a particular concept. It is paradoxical that, in scientific disciplines, many scientists do not follow a scientific approach to establish the concepts supporting their theoretical frameworks and hypotheses. In the article "The Habitat Concept and a Plea for Standard Terminology," Hall, Krausman, and Morrison (2016) present the difficulties posed by the lack of conceptual precision in the communication between disciplines, since this can misrepresent the actual meaning of the concepts. Besides, this lack of accuracy can spawn nonstandard and ambiguous responses of legal and public policies to questions addressing sustainability, operational processes standardization, knowledge and technology transfer and other administrative, legal, social and cultural factors.

Murcia et al. (2014) introduced a similar line of argument in their article "A critique of the 'novel ecosystem' concept," where they stress the repercussions of adopting uncritically new concepts and approaches, based on opinions, unproven assumptions and unjustified conclusions lacking required essence and supporting evidence. This may lead to ambiguous claims and wrong conceptions with potentially disruptive political implications.

A concept from perspective of science expresses the universal in its maximum abstraction, acquiring a formality with value of class from the logic of science. These formal concepts enable researchers in establishing classifications and ordering of the world (Flores 2011; Putnam 1984), in contrast to the **concepts** resulting from the particular experiences of each researcher, that is subjective concepts. Essentially, this is the problem, owing to the fact that a trend toward polysemy exists, which hinders optimal communication. One of the attributes of science is the identifying conventionally equal and universal meanings (Ferrater-Mora ; Honderich and Trevijano 2008).

Science attempts to articulate its concepts through a adjusted language to specific content with no mistakes and minimal possibilities of differing interpretations, using precise language and optimized simplicity, without using the defined word itself or its derivatives and avoiding exception rules in the definition. The effort to unify concepts and terminology is crucial to build significant statements and progress in science. Therefore, the fundamental concepts must be well defined and thereby, well understood.

In addition to the lack of unity in the semantic concept, there is no operational concept. It refers to the specific process by which the measurements that allow the precise identification of the study object are obtained. The operational concept allows its praxis, indicating the state variables and the formulation of methods for its study and allowing researchers to conduct comparative analyses how to measure its variables (Ferrater-Mora ; Tamayo 2011).

Objective

The objective of this article is to present a formal and operational concept of agroecosystem as a holistic, irreducible and basic unit, for its analysis by those who work in sustainable agriculture and contribute to the good living and development of agroecology as a scientific discipline.

Methods

This work was executed in four stages as follows:

(1) First, a review of the most relevant literature since the 1970s on the historical trajectory of the agroecosystem concept was performed.

(2) A total of 37 research articles published from 2005 to 2013 were selected, all of which found in Science Direct, Academic Search Complete, Ebrary, Agecon Search, Springer Journal, Science Online and JSTOR (Journal Storage) databases. The search filters were configured in order to find the term "agroecosystem" in the title, abstract or keywords. Based on the exhaustive review, the articles were grouped according to affinity criteria, if the definition had been explicitly or implicitly stated in the articles.
(3) In a second search for articles published from 2005 to 2019, carried out using the Google scholar platform, the definitions identified in stage 2 were validated and adjusted. In total, 1498 scientific articles were identified and regarded as the sample universe. From this, 10% of the articles were selected through a uniform stratified sampling, using the year of publication as a criterion and discarding those that were not research articles. Then, on the second and third stages, a total of 157 articles were thoroughly reviewed. Subsequently, and according to the criteria identified, the definitions were grouped into six concepts of agroecosystems. Besides, those articles that did not present a concept definition but included the word "agroecosystem" in the title, abstract or keywords were considered.
(4) Finally, a formal and operational concept of agroecosystem is proposed from the perspectives of epistemology, heuristics and formal logic – hoping that this approach will be analyzed for contributing to the perspective proposed by Holdridge (2009) and Hall, Krausman, and Morrison (2016).

Results and discussion

Analysis of the historical trajectory of the agroecosystem concept (stage 1)

Since before the 1970s, the agroecosystem has been conceptualized as a modified ecosystem by humans, at different levels of intensity, to use natural resources in the natural agriculture, livestock, forestry production and rural services processes, focusing on the ecological processes. This approach refers to the concern for the operation and the impacts of the agricultural green revolution on nature, masterfully expressed in 1962, the book Silent Spring (Carson 2002). Several ecologists brought back the concept of agriculture enunciated decades ago, as a process involving the modification of ecosystems at different levels of intensity by humans to meet their needs. Therefore, an agroecosystem is considered a farm field, on the basis of an ecosystem-centric approach, whose production and performance are a function of ecological processes such as nutrient cycles, predator – prey interactions, competition, commensalism, and successional changes (Altieri 1983, 1999; Hecht 1999; Cox and Atkins ; Elliott and Cole 2003; Gallopin 1995; Gliessman 1990; Gliessman et al. 2015; Hart 2016; Hernández 1999; León 2014; León, Mendoza, and Córdoba 2014; Odum and Sarmiento 1979; Perfecto and Vandermmer 2015; Sarandón 2014; Vandermeer 2011; Xu and Mage 2017).

However, this is a narrow view, so its conceptualization has been proposed from broader perspectives, such as economic, sociological, anthropological and cultural (Vilaboa 1999; Xu and Mage 2017). From the cultural approach, León (2014, following Taylor, 1871), suggests considering symbolic – organizational–technological structures. The symbolic structures encompass myths, habits, religions, philosophy, ideologies, science and law, representing human interpretations and efforts to understand the web of life, giving rise to the organizational processes of societies. As a result, these structures constitute the foundations where with the individual, the community and the society establish their perspective and relationship with nature, either of integration (monist conception) or submission and exploitation (dualist conception). The type of knowledge, social and production organization, technology and legal regulations for the intervention and use/exploitation of nature are articulated on the basis of these perspectives and relationships (Correa 1993; Gaviria 2013). Technology, as an applied science, addresses the complexity of human thought and action to become an instrument, tool, equipment, machinery or system. Furthermore, it is indicative of the interests, social conflicts, power struggles, economic and military domains, and world views of those who produce and put them into effect. Therefore, technology may not be apolitical or culturally neutral (Schumacher 2014; Tosi 1972).

In that regard, Toledo and Moguel (1992) stressed the crucial need to identify, categorize and analyze concrete units in the natural spaces that are concurrently valid and generalizable. The creation and generalization of a model from this unit would allow for the integration of information on key or controlling variables, processes and properties, becoming a focal concept for research (Elliott and Cole 1989). Besides its natural condition, this unit operates as the material, energy and as the information base point of the production processes. Therefore, its evaluation will help understand its productive potential, as well as its vulnerabilities, allowing the farmer to apply several strategies to optimize production through the sustainable management of its base resources. This natural unit must be identified in nature, along with the conceptualization integration of its strategies and farmer management, and constitute the reference operational unit to assess the sustainability of the production processes. Therefore, it must be unequivocal and unambiguous.

Holdridge (2009) stated that "all sciences have a basic unit of study." Their definition provides the theoretical and operational principles of a single area of knowledge. Many have already established it and reported studies based on it, such as biology which involves the cell, or quantum physics that constitutes the atom and elementary particles. However, in some sciences, the basic unit of study has not been defined, or a consensus has not been reached on it. Groups where evolutionary processes have been actively involved are bound to show some subjectivity, however, if the basic unit has been appropriately chosen, on-going studies will bring about a general consensus regarding to the correct definition of each unit.

Some of the criteria used to identify and classify agroecosystems have been as follows (Cleves et al. 2009; Elliott and Cole 1989; Gallopin ; Hart 1985; Hernández 1999; Altieri 1983; Instituto de Recursos Mundiales 2008; León 2014; Xu and Mage 2013): productive activity (crops, livestock, forestry or a combination); plant cover or main crop (coffee, palm, etc.); socio-economic (farming, corporate, agro-industrial, colonization, indigenous, raizal communities, etc.); type of agriculture (conventional, ecological, agroecological, organic, permaculture, etc.); legal-administrative (property); political-administrative (village, region, etc.); natural (basin); unit of production and management (plot, meadow); intensity of production (extensive, intensive or intermediate between these two) in function of the reference resource, be it land, soil, water or energy, among others.

Predominant agroecosystem concept in research articles (stage 2)

The use of the word agroecosystem in titles, keywords and abstracts of research articles has been increasing between 2005 and 2019. Table 1 indicates the proposed definitions extracted from the reviewed articles.

According to Table 1, a summary of the definitions and concepts of agroecosystem is presented, grouped as per the following affinity criteria:

- Determined by cover crop of interest: This is the most frequent definition, present in 25% (39) of the articles. Agroecosystems are named according to the cover crop of interest such as coffee (Gordon et al. 2007; Hernández-Martínez, Manson, and Hernandez 2009, among others), corn (Sarabia et al. 2017) and palm (Puan et al. 2011), among others. This definition would imply that the agroecosystem would change with changes in the crop. In most of the studies, the concept was implicit, except for two works: Guzmán et al. (2018) define the agroecosystem as "large areas where the native fauna and flora have been totally or partially replaced by agriculture and livestock, covering more than 50 million km^2, or approximately 25% of the total ground surface." Likewise, Gorosito, Bermudez, and Busch (2007) define the agroecosystem as "landscapes with a high intensity of land use that sustains large food resources, which could favor threatened species or pests." Including the word "agroecosystem" in the title, abstract or keywords was not necessary in 32% of the articles within this group, since it was not central to the research and was not used again throughout the article.

Table 1. Different definitions of agroecosystems grouped according to affinity criteria from research articles published between 2005 and 2019.

Concept	Reference*	Relative importance of the concept (%)
Determined by cover crop of interest	Ludy and Lang, 2006; Fernández et al., 2007; Gordon et al., 2007; Pérez-de La Cruz et al., 2007; Perreault et al., 2007; Speratti et al., 2007; Philpott et al., 2008; Hernández-Martínez et al., 2009; Buyer et al., 2010; Singh & Ghoshal., 2010; Alonso et al., 2011; Puan et al., 2011; Youkhana & Idol., 2011; Appiah., 2012; Castro-Luna & Galindo-González, 2012; Blanco et al., 2013; Chapman et al., 2013; Delegido et al., 2013; De Lima et al., 2014; Maul et al., 2014; Michalko & Pekár., 2015; Navedo et al., 2015; Dao, 2016; Guzmán et al., 2016; Junqueira et al., 2016; Morelle et al., 2016; Lecq et al., 2017; Loreto et al., 2017; Pelak et al., 2017; Perronne et al., 2017; Sarabia et al., 2017; Chaudron et al., 2018; Gorosito et al., 2018; Kopler & Malkinson, 2018; Andreo et al., 2019; Giuliano & Bogliani, 2019; Niell et al., 2019; Piña et al., 2019.	25%
System whose components interact and are modified by humans for their own benefit	Choudhury et al., 2006; Jiménez et al., 2008; Kotova et al., 2008; Moonen & Bàrberi, 2008; Perovic et al., 2010; Debeljak et al., 2011; Sánchez-Moreno et al., 2011; Van Apeldoorn et al., 2011; Khumalo et al., 2012; Zhu et al., 2012; Sabatier et al., 2013; Shukla et al., 2013; Eubanks & Finke, 2014; Tittonell, 2014; Cicuéndez et al., 2015; Palacios-Agundez et al., 2015; Perfecto & Vandermeer, 2015; Smith, 2015; Tribouillois et al., 2015; Arif et al., 2016; Shukla et al., 2016; Ashworth et al., 2017; Bajard et al., 2017; Wagena et al., 2017; de Sosa et al., 2018; Reyna-Ramírez et al., 2018; Santos et al., 2018; Hirte Jet al., 2018; Myrgiotis et al., 2018; Boone et al., 2019; Li et al., 2019; Marullet al., 2019; Marull et al., 2019; Seipel et al., 2019; Wu et al., 2019.	23%
Production system, focused on production and management practices	Lobeet al., 2005; Mulder et al., 2005; Meyling & Eilenberg, 2006; Lores et al., 2008; Aavik & Liira, 2009; Rodrigues & Gehring, 2010; Scanlon et al., 2010; Aguilar-Jiménez et al., 2011; Bhardwaj et al., 2011; Prieto-Benítez & Méndez, 2011; Ouyang et al., 2013; Acosta-Martinez et al., 2014; Dong et al., 2014; Speelman et al., 2014; Singh et al., 2015; Turmel et al., 2015; Zhang et al., 2015; Cao et al., 2016; Crews et al., 2016; dos Santos et al., 2016; Winkel et al., 2016; Lopez-Collado et al., 2017; Sajadian et al., 2017; Xie & Lakkenborg, 2017; Yang et al., 2017; Bach et al., 2018; Cobb & Wilson, 2018; He et al., 2018; Christou et al., 2018; Halstead et al., 2019; Liu et al., 2019; Lizaga et al., 2019; McKay et al., 2019; Rao et al., 2019.	22%
No clear concept	Velasquez et al., 2005; Zuazo et al., 2005; Naveed et al., 2007; Zhou et al., 2012; Amossé et al., 2013; Wieland et al., 2013; Pérez-Suárez et al., 2014; Zhang et al., 2014; Zuluaga & Rodewald, 2015; Maltais-Landry et al., 2016; Rashid et al., 2016; Ribas e Ribas et al., 2016; González-Varo & Vilà, 2017; Hanifet al., 2017; Hamelet al., 2018; Jouni et al., 2018; Lu et al., 2018; Portilho et al., 2018; Qi et al., 2018; Wang et al., 2018; Feng et al., 2019; Haran et al., 2019; Hu et al., 2019.	16%
Climatic zoning and biophysical determination	Tognetti et al., 2006; Steenwerth & Belina., 2008; Álvaro-Fuentes et al., 2009; Barbarick & Ippolito, 2009; Barbarick et al., 2012; Álvaro-Fuentes et al., 2013; Acosta-Martinez et al., 2014; Navas et al., 2014; Ripoche et al., 2015; Campos et al., 2016; Novara et al., 2016; Quijano et al., 2016; Álvaro-Fuentes et al., 2017; Wyckhuys et al., 2017; Álvaro-Fuentes et al., 2018; Carranza-Gallego et al., 2018; min Liang et al., 2018; Daam et al., 2019.	12%
Areas delimited by legal, administrative, or political-administrative criteria	Valdés et al., 2009; Gravina and Leyva, 2012.	1%
Delimitation according to socio-economic categories	Casas-Cázares et al., 2009.	1%

*(see appendix for the bibliography cited in the table 1).

- System whose components interact and are modified by humans for their own benefit: This definition was found in 23% (35) of the reviewed articles, covering different topics ranging from agrobiodiversity assessments, nutrient cycle, CO_2 emission, evaluation of the soil and system efficiency, among others. Five articles within this category defined the agroecosystem concept explicitly. For example, according to Li et al. (2019), "Agroecosystems are semi-artificial ecosystems that are important sources of provisioning, and regulatory, cultural and supporting services."
- Production system, focused on production and management practices: From the reviewed articles, 22% (34) of them were grouped under this concept, of which only Rao et al. (2019) proposed a definition of the agroecosystem as "a homogenous geographical area, wherein the production environment of the region in terms of the agro-climate, resource endowments and socio-economic conditions is homogenous, and the majority of the farmers have similar production constraints and research needs." On their work, Crews et al. (1979) propose a comparison between agroecosystems, characterized by their management, to assess the impact on the ecological dynamics of the system through a detailed analysis of the nitrogen cycle. Notably, in 21% of the articles within this category, mentioning "agroecosystems" would not have been necessary. In this sense, the study by Cao et al. (2016) is noteworthy, as they recommend the cultivation of vegetables in greenhouses to reduce the heavy metal contaminations in the irrigation water of agroecosystems in two regions of China.
- No clear concept: In 16% (24) of the articles reviewed, the concept of agroecosystem was neither used explicitly nor implicitly, however, the word was found in the title, keywords or abstract. The detailed review of these studies indicates that this term was not a key concept for the research as its interest is related to another topic.
- Climatic zoning and biophysical determination: In this case, 12% (18) of the articles refer to agroecosystems as regions that can be separated by biophysical variables, especially those related to climate. For example, Mediterranean mountain agroecosystems by Navas et al. (1979), semiarid Mediterranean agroecosystem, by Álvaro-Fuentes et al. (2013) or savannah agroecosystems by Ripoche et al. (2015), among others. Álvaro-Fuentes et al. (2018) mention a Mediterranean agroecosystem in their article. However, what it actually assesses is the incorporation of pig slurry in the plots and its influence on CO_2 fluxes. In 47% of the articles that fall within this category, the use of the term agroecosystem was not necessary for research purposes.
- Area delimited by legal, administrative, or political-administrative criteria: Two papers were found in this category, corresponding to 1% of the

reviewed articles. For example, Valdés et al. (2009) use the term to refer to farm and ecosystem interchangeably. However, the work is carried out at the farm scale.

- Delimitation according to socio-economic categories: In one work (1%), authors mention regarding smallholding farming agroecosystems, and propose the following definition for agroecosystem: "the basic unit for the design and evaluation of sustainability, according to its vision and definition. It is the biophysical area where socio-economic relationships are established between people to transform nature and themselves, in order to obtain products, by-products and other goods for the perpetuation of generations in a single area" (Casas-Cázares et al. 2009). Although there is an explicit definition of agroecosystem, three peasant communities were compared and treated as synonyms of agroecosystems and regions in said the abovementioned article.

The general situation, shown when establishing the concepts of stages 1 and 2 in this study, evidences the presence of polysemic concepts. This is owing to the differential attributes that the basic units identified as agroecosystem will, on the basis of the variables, processes, rates of change or response, and the level of detail, be investigated, operated and transformed. In addition, it has been confirmed that the term agroecosystem is employed to refer to different political-administrative, natural and/or legal basic units. This is ensured at different spatial levels, from the plot to regions and the planet, or according to any of the criteria of particular interest for each author (León 2014; Xu and Mage 2017), given the arbitrary nature of the limits of ecosystems (Gliessman et al. 2015). The agroecosystem of Naveed et al. (2007) (agroecosystem of cotton), who defined it implicitly according to the cover crop of interest, it is not comparable to the agroecosystem of Álvaro-Fuentes et al. (2009), who defined it based on climatic zonation (Mediterranean semi-arid agroecosystem). It is evident that there are not an universal concept, or a less pretentious one: an agreed upon concept or one that can be validated by researchers.

Many of the concepts cited in the bibliographic review and in the research articles refer to the agroecosystem as a modified ecosystem, as production systems or by the cover crop of interest. These concepts can be classified as logical semantic concepts that refer to the meaning of the words or formal representations, among other linguistic symbols. However, there is a lack of semantic unity in the concept, in addition to the absence of an operational concept of agroecosystem that allows its praxis and indicates how to measure its variables and, specifically, the state variables.

Toledo and Moguel (1992) refer to the need to "opt for concepts, terms and methodologies for the specific field of rural production for the application of the main paradigms derived from the ecological theory, physical geography and landscape ecology," and argue that there is neither an "agreement on a general definition of basic management units," nor "available information to make accurate calculations on the capacity, in terms of their physical-biological thresholds, on the natural landscape basic units to support diverse management practices, despite that there are many terms referring to it in the literature" (such as load or carrying capacity). The authors stated the following: *Thus, for example, the agroecosystem conceptualization as a modified ecosystem is associated with establishing the limits of the ecosystem in order to set the benchmarks of the area and other factors that allow for making accurate calculations on productive capacities, vulnerability, threats and sustainability* (Toledo and Moguel 1992).

It is important to establish the theoretical framework for the concept of agroecosystem. Specifically, as it belongs to the agroecology, it corresponds to that of systems theory. Therefore, the concept of agroecosystems must be framed in the principles of the hierarchy theory, elaboration or the study of components (with emphasis on the interactions between them), the synthesis or systemic emergency, and the teleology or goals established by the producer. The latter is the beacon for the system analysis owing to the fact that it is the goal which determines the components comprising it, the connections between them and the structure that helps achieve it (Dalgaard, Hutchings, and Porter 2003; Johansen 2002, 2004b; Odum and Sarmiento 1998; O'neill et al. 1986; Saravia 2014).

Agroecosystem: towards the construction of a semantic concept

From the syntactic approach, the agroecosystem places agriculture in the ecosystem, which leads to conceptualizing the agroecosystem from the modification (artificialization) of the ecosystem, with an anthropic goal through a plan (Hart 1985). To explain the scope of this concept, the agroecosystem refers to agriculture as a cultural process set up in nature, reflected in an ecosystem operated by humans through an agrotechnological management system (Altieri 1983), for the purposes of achieving certain objectives and goals, related to the context and culture in which it is inserted. Therefore, agroecosystem is a product of the culture – nature interaction, constituting as a systemic emergency, a complex socio-ecological system (Figure 1). Culture is expressed according to the society's perception on nature, which is related to the socio-economic system and linked values and in the generated and validated knowledge to intervene in nature and the agrotechnological system management. This consequently transforms the ecosystem to attain the anthropic goals of a given culture (Capra 1982; Gastó 1980; Schumacher 1984; Tosi 1972).

To illustrate, the green revolution and the incorporation of transgenic plants in agriculture, which currently predominates, is the product of a perception of nature, based on a Cartesian dualist paradigm that places humans outside of nature (Capra 1982) and, in the chrematistic economy with its concomitant social values, such as consumerism and the maximization of chrematistic profitability, degrading and destroying nature either through its exploitation or by using it as a sink for the externalities of the production process (Daly 2003; Leonard 2014). It is in the agribusiness sector where all natural processes are replaced by input and technology (Vélez 2004). Meanwhile, Amerindian cosmogonies, under a monistic paradigm, consider humans as integrated with nature, conceiving nature as the *Pachamama*. This constitutes the fundamental explanatory principle of the cosmovision of native Andean peoples in South America. *Pacha* in Quechua means earth, world, cosmos; and *mama* means mother. Thus, *Pachamama* stands for "Mother Earth." This is the essence of the belief system and the ecological-social behavior of the indigenous peoples of the Central Andes in South America (Correa 1993; Escobar 1996; Merlino and Rabey 1993). This could be supplemented by the analysis of the interaction between society and nature, the agroecosystem being its product, if the base of this paradigm is considered religious (as established in Genesis) or whether it is based on the environmental and green economy; among the many paradigms that may arise from the diversity of cultures that inhabit the planet (Figure 2).

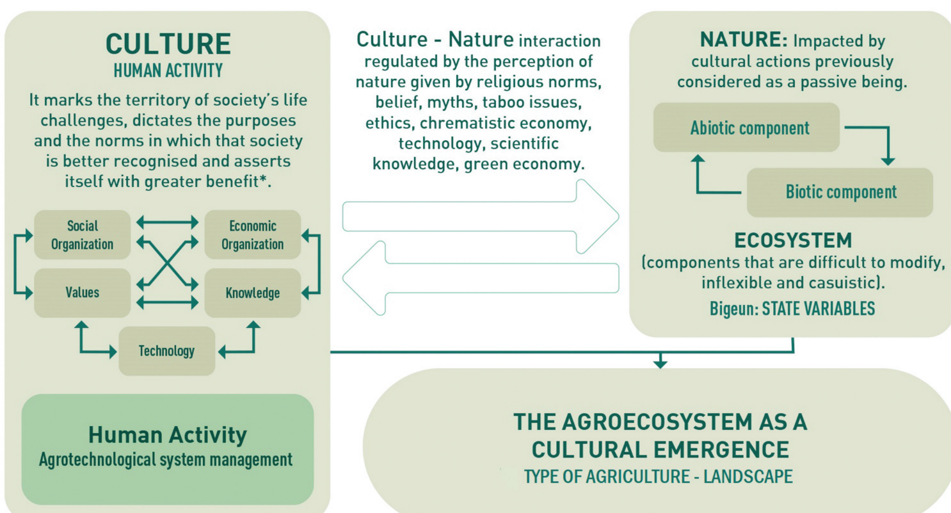


Figure 1. The agroecosystem as a systemic emergence product of the interaction between culture and nature, which determines types of agriculture and the rural landscape. * Elnadi and Rifaat (1996).

Similar analyzes could be made of the knowledge of peasants, indigenous peoples, smallholders, fisherfolk, pastoralists, landless workers, and other agroecological practitioners around the world. This knowledge is expressed through the management proposals of the ecosystems the people inhabit.

Agroecosystem: Toward the construction of an operational concept

Although the semantic concept allows us to understand the agroecosystem, it is necessary to delimit it in space and time as per its biophysical connotation, in terms of its state variables. Therefore, enable setting up the agroecosystem as a basic unit of nature transformation into agricultural production processes and natural resources utilization. The operational concept allows to identify, delimit, measure, characterize and evaluate its condition, trend, vulnerability and sustainability, as well as to perform comparative studies, among other factors (Ferrater-Mora ; Tamayo 2011). The operational concept is established following Nava, Armijo, and Gastó (1979), Gastó (1980), Gastó, Vélez, and D'angelo (1997).

For the construction of an operational concept, it is proposed following two steps: in the first, identifying the ecosystem through it delimitation by biophysical variables that are difficult to modify or state variables; and in the second, defining the management of the delimited ecosystem, as expression of culture.

In the first step, agriculture entails the transformation of any ecosystem from a state (Ei) at a point in time (t_i), toward an objective state (Eo) at a subsequent time $t_{(i+n)}$, for the achievement of anthropic purposes. For example, a type of agriculture that, besides being productive and profitable is also sustainable, not very vulnerable, resilient and allows for managing risks, such as those caused by climate change contributing to the good living. This transformation is implemented by operators (w_j) applied in a certain manner or ways (p_j), referring to procedures, tools and technologies that correspond to a specific agrotechnological management system (AMS), in order to modify those factors and state variables that determine the performance of the ecosystem Ei and, consequently, the achievement of the anthropic purposes. If the application of the operators ceases, the ecosystem will tend to an uncertain state E_x in a point in time t. This principle can be formulated as follows:

$$Ei_{(ti)} \overset{wjpj}{\rightarrow} Eo_{(ti+n)} \rightarrow Ex_{(t)}$$

Where: $Ei \ldots Ex$ is the ecosystem, w_j is the operator and p_j refers to the procedures, tools and technologies.

The state variables can be categorized by their level of control over the production processes or other variables, and/or by the challenge of their management and transformation, defining components that are difficult to modify, flexible or casuistic. The latter correspond to those of low significance in the determination the ecosystem status (Figure 2). For example, some of the variables related to components that are difficult to modify are: the latitude, which determines the amount of radiant energy received by the ecosystems and its annual cycle ($X1_{(t)}$); the environmental humidity ($X2_{(t)}$), being the product of the interaction between temperature and evapotranspiration which defines the provinces of humidity (Holdridge 2009); or the topography ($X3_{(t)}$) which determines the extent of the law of gravity in edaphic processes such as the erosion and water fluxes, etc. Each variable must be handled or modified for them to meet the attributes that *Eo* should have. In this sense, the knowledge of the nature of the variables, their qualitative and quantitative assessment, as well as their interactions with the state variables and the environment, is essential. This principle can be formulated as follows (Gastó 1980) (the ecosystem transformation).

$$\begin{aligned} Ei_{(ti)} &= \left\{X_{1(ti)}, X_{2(ti)}, X_{3(ti)}, \ldots X_{w(t)}\right\} \rightarrow E_0 \\ &= \left\{X_{1(ti+n)}, X_{2(ti+n)}, X_{3(ti+n)}, \ldots X_{w(t+n)}\right\} \end{aligned}$$

Where: E_j is the ecosystem; $X_1 \ldots X_\omega$ are the ecosystem variables.

Therefore, the first component of the operational concept of agroecosystem requires the knowledge and correct selection of the key state variables or the productive processes controllers, articulated in a specific structure. This will make it possible to establish homogeneous basic units for designing and evaluating the different types of agriculture.

In the second step, according with Hart (1985), the cropping systems are not the only roadmap to define the agroecosystem, but it is the farmer's management which, conditioned by biophysical variables (e.g. the soil), can be an important guideline for setting its limits. Therefore, this implies that it is the soil type the factor allowing for the establishment of ecosystem state variables, arbitrating, in this example, the physical delimitation of the agroecosystem.

These homogeneous and discretionary natural basic units or biogeostructural units (BIGEUN) have differential capacities to accommodate different types of technologies without being degraded, in terms of technological intensity or the agrotechnological management system (e, w_j, p_j), i.e., technological receptivity (Vélez and Gasto 1999). Thus, the operational concept of agroecosystem is the integration of the natural basic units, in its state variables (BIGEUN), with the AMS that applies in that specific BIGEUN for the achievement of anthropic purposes (Figure 2).

The identification and delimitation of the agroecosystem (AES) in the field is shown in Figure 2. The first thing (2a) is to identify how the farmer has arranged his farm in spatial units (SUs, e.g. paddocks, plots, ranches, etc.), where the productive activities are carried out with its corresponding AMS. Then, the property zoning in BIGEUNs is carried out (2b), which overlaps the SUs with its corresponding AMS (2c), thereby obtaining the agroecosystems (2d). To cite an example, two BIGEUNs can be found in SU 1, with different slopes and effective depth, making these previously mentioned overlaps. Henceforth, AES 2 with slopes ranging between 12.5 and 25% and with an effective depth lower than 50 cm is more vulnerable to grazing than AES 1 (with slopes lower than 3% and an effective depth greater than 100 cm). Therefore, livestock farming in AES 2 is less sustainable both economically, due to production costs and productivity, and ecologically, due to soil degradation (erosion and compaction). Nevertheless, livestock farming can be carried out, changing the AMS, for example. Thus, in AES 2, mowing pastures (as protein banks) can be settled, for their supply in the stables when the cattle are grazing in AES 1.

This conceptualization allows the agroecosystem to be hierarchically integrated with other territorial units (Figure 3). Although this hierarchical

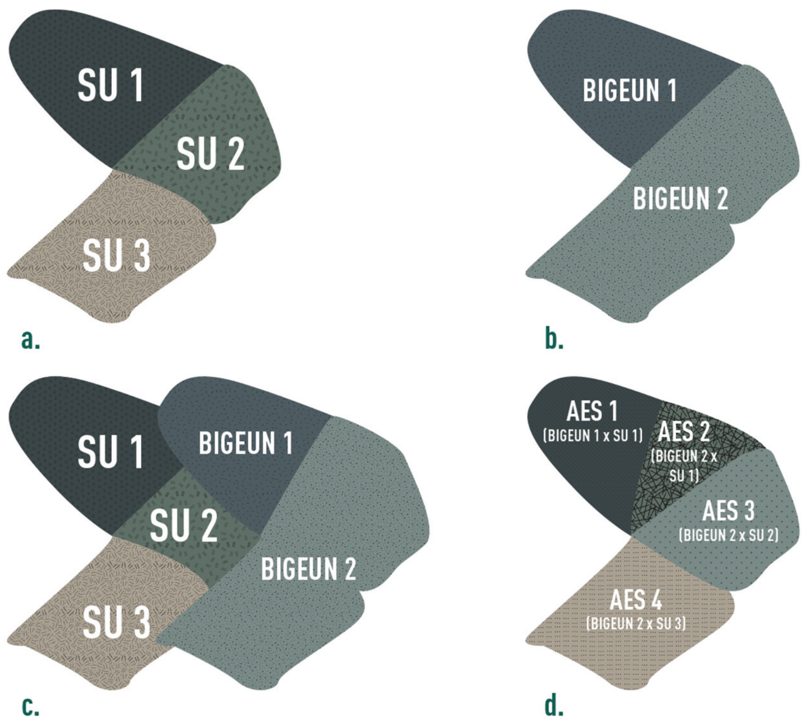


Figure 2. Identification and delimitation of the agroecosystem (AES) in the field. 2a) represents how the farmer has arranged his farm; for example, spatial unit 1 (SU 1) corresponds to grazing pastures managed with its corresponding AMS; SU 2 represents perennial fruit trees with its corresponding AMS, while SU 3 deals with short-term crops with its corresponding AMS. 2b) representation of the property in homogeneous units (BIGEUNs) delimitated by state variables (e.g. by slope and effective depth of the soil), for example, BIGEUN 1 has slopes lower than 3% and a depth greater than 100 cm; BIGEUN 2 has slopes ranging between 12.5 and 25% and an effective depth lower than 50 cm. 2c) Integration of SUs with their corresponding AMS and BIGEUNs. 2d) four resulting agroecosystems (AMS).

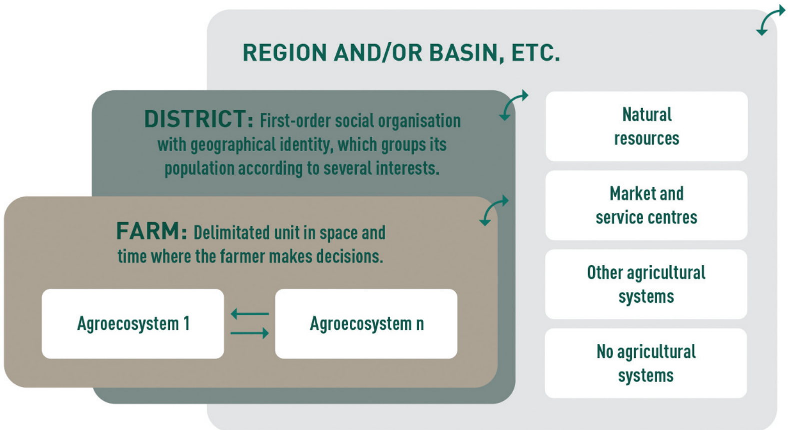


Figure 3. Hierarchical structure of the intervention units with the agroecosystem as the basic unit (Source: Adapted from Vélez and Leiva 1999).

structuring may be administrative or political-administrative, it can also be ecological or geographical (e.g., a basin and/or life zones, etc.). One of the key aspects of this hierarchical structuring is the avoidance of polysemy, since each of these units has specific legal, instrumental, operational and epistemological concepts. In this hierarchical structuring and in concordance with the postulates of systems theory, the study of agroecosystems must be done within the farm framework, since this is under the guidance of the farmer, who establishes the goals and design of the agroecosystems. Consequently, the farm functioning is framed in the hierarchical level that contains it, being it the district, the municipality and/or a region, etc.

With this conceptual framework, different production systems have been already evaluated in Colombia (Genes-Arrieta et al. 2015; Dávila, 2016; Madrid et al. 2017; Barrera 2019), especially at the farm level. This allows for conducting comparative analyses between different types of agriculture, since what is evaluated is the management with respect to the natural conditions of the property. This comparative analysis enables policy making, strategies and promotion programmes toward those agroecosystems whose management corresponds to its nature's capacity.

Conclusion

Agroecosystems constitute culturally built responses to local ecosystems, to the interrelationship between the rural and the urban, to the placement of the locality in a broader commercial pattern and to national and international agricultural policies. Thus, agroecosystems are the result of specific connections between economic, social, ecological, cultural, political and technological dimensions. All this constitute nodal points that allow the transfer from one dimension to another, where ecological matters are transformed into specific economic positions and vice versa. Consequently, the meaning of agroecosystem has a socio-economic and cultural connotation, valuation, appropriation and usufruct of the renewable natural resources by human beings and society. It constitutes a node for the exchange of values between the economic, social, political, ecological, environmental and cultural dimensions.

The agroecosystem is a homogeneous natural unit (Biogeographical structural Unit – BIGEUN) with specific coordinates and with an embedded system for agrotechnological management system (SAM), whose goal is determined by the farmer, being this a holistic, implacable, and particular basic unit of labor of the agroecology and agricultural science which integrates production processes and competencies for sustained agriculture. The agroecosystem is commensurable, with an identity of its own, from which a hierarchical structure is built by levels of complexity, which takes us to the farm, the district and the region, from a territorial, systemic and holistic approach (Vélez and Leiva 1999).

Acknowledgement

We are grateful to A. Calle, J.H. Madrid, S. Vélez, M. García and the Research Group Conservación y Manejo de Agroecosistemas – CyMA, with whom we had valuable discussions about the Agroecosystem subject. We also thank the Research Vice-deanship from the Agricultural Sciences Faculty of the Universidad Nacional de Colombia for his support in writing the manuscript. Finally, we thank the anonymous reviewers for stimulating discussion on the subject.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Velez Leon Dario http://orcid.org/0000-0002-9010-6866
Muriel Sandra B http://orcid.org/0000-0002-1938-0096

References

Alpa, G. 1994. General Principles of Law. *Annual Survey of International & Comparative Law* 1:1. Article 2.

Altieri, M. 1983. *Agroecología. Bases científicas de la agricultura alternativa*, pp. 184. Editorial: CETAL.

Altieri, M. 1999. *Agroecología. Bases científicas de la agricultura alternativa*, 339. 5ta. ed. Editorial: Editorial Nordan: Montevideo.

Álvaro-Fuentes, J., F. J. Morell, E. Madejón, J. Lampurlanés, J.L. Arrúe, and C. Cantero-Martínez. 2013. "Soil biochemical properties in a semiarid Mediterranean agroecosystem as affected by long-term tillage and N fertilization." *Soil and Tillage Research* 129: 69–74. doi:10.1016/j.still.2013.01.005.

Álvaro-Fuentes, J., D. Plaza-Bonilla, and C. Cantero-Martínez. 2018. Pig slurry incorporation with tillage does not reduce short-term soil CO2 fluxes. *Soil and Tillage Research* 179:82–85. doi:10.1016/j.still.2018.02.002.

Barrera, M. 2019. "Evaluación de la Multifuncionalidad de la agricultura de los sistemas de producción tradicional del occidente cercano de Antioquia - Colombia." MSc. thesis., Universidad Nacional de Colombia.

Bawden, R., and R. Ilison. 1992. *The purposes of field-crop ecosystems: Social and economics aspects. En: Ecosystems of the World: Field Crop Ecosystems*. In ed. P. C. J, 11–36. Amsterdan: Elsevier Science Publisher B.V.

Cao, C., X. P. Chen, Z. B. Ma, H. H. Jia, and J. J. Wang. 2016. Greenhouse cultivation mitigates metal-ingestion-associated health risks from vegetables in wastewater-irrigated agroecosystems. *The Science of the Total Environment* 560-561:204–11. doi:10.1016/j.scitotenv.2016.04.044.

Capra, F. 1982. *El punto crucial. Ciencia, sociedad y cultura naciente*, 514. Barcelona: Integral.

Carson, R., 2002. Silent spring. Boston:Houghton Mifflin1907–64

Casas-Cázares, R., F. González-Cossio, T. Martínez-Saldaña, E. García-Moya, and B. Peña-Olvera. 2009. "Sostenibilidad y estrategia en agroecosistemas campesinos de los valles centrales de Oaxaca." *Agrociencia* 43: 319–31.

Cleves, J. A., J. Toro, M. L. F, and T. León. 2017. La Estructura Agroecológica Principal (EAP): novedosa herramienta para planeación del uso de la tierra en agroecosistemas. *Revista Colombiana de Ciencias Hortícolas* 11. 441–49. DOI. doi:10.17584/rcch.2017v11i2.7350.

Coleman, D., and P. Hendrix. 1988. *Agroecosystems processes. A comparative view. En: Concepts of ecosystem ecology*. In ed. L. R. Pomeroy and J. J. Alberts, 384. New York: Sprimger-Verlag.

Correa, F. 1993. "La selva humanizada." In *Bogotá: Fondo Editorial CEREC–Instituto Colombiano de Antropología*, edited by F.Correa, 259. Bogotá: Fondo Editorial CEREC.

Cox, W., and M. Atkins. 1979. *Agricultural ecology. An analysis of world food production systems*, 731. San Francisco-California: W.H.Freeman & Co Ltd.

Crews, T. E., J. Blesh, S. W. Culman, R. C. Hayes, E. S. Jensen, M. C. Mack, M. Peoples, and M. E. Schipanski. 2016. Going where no grains have gone before: From early to mid-succession. *Agriculture, Ecosystems & Environment* 223:223–38. doi:10.1016/j.agee.2016.03.012.

Dalgaard, T., N. Hutchings, and J. Porter. 2003. "Agroecology, scaling and interdisciplinarity." *Agriculture, ecosystems & environment* 100 (1): 39–51. doi:10.1016/S0167-8809(03)00152-X.

Daly, H, ed. 1989. "Introducción a la economía en estado estacionario." *Economía, Ecología y ética. Ensayos hacia una econmía en estado estacionario,* 7–43. ISBN: 968-16-3291-5. México D.F: Fondo de Cultura Económico, S. A.

Dávila, J.C. 2016. "Variables Explicativas de la Vulnerabilidad Biofísica y Socio Económica al Cambio Climático en Agroecosistemas de la Cuenca del Rio Grande -Antioquia." MSc. thesis., Universidad Nacional de Colombia.

Elliott, E. T., and C. V. Cole. 1989. A Perspective on Agroecosystem Science. *Ecology* 70 (6):1597–602. DOI. doi:https://doi.org/10.2307/1938092 .

Elnadi, B., and A. Rifaat. 1996. "What is develpment?." *The Unesco Courier* Sept: 8–9.

Escobar, A. 2012. Cultura y diferencia: la ontología política del campo de Cultura y Desarrollo. *En: Wale'keru* 2: 7–16. Consultado el 04.11.2020. Available in. https://dugi-doc.udg.edu/bitstream/handle/10256/7724/WALEKERU-Num2-p7-16.pdf

Facultad de Ciencias Agrarias, Universidad Nacional de Colombia Sede Medellín. Ingeniería Agronómica - Objetivo. Accessed 15 Jan 2022. https://cienciasagrarias.medellin.unal.edu.co/ingenieria-agronomica.html

Ferrater-Mora, J. 2015. *Diccionario de Filosofía*. Editorial Ariel: tercera edición, España.

Flores, G. Formando investigadores. Accessed 27 Dec 2021.

Gallopin, G. C. 1995. The potential of agroecosystem health as a guiding concept for agricultural research. *Ecosyst Health* 3:129–40.

Gastó, J. 1980. *Ecología. El hombre y la transformación de la naturaleza*, 573. Santiago de Chile: Editorial Universitaria.

Gastó, J., L. D. Vélez, and C. D'angelo. 1997. Gestión de recursos vulnerables y degradados. *En: Libro Verde: elementos para una política pública agroambiental en el Cono SUR/Programa Cooperativo para el Desarrollo Agropecuario del Cono Sur (PROCISUR)*. PROCISUR. Págs226 p 75–116. Montevideo.

Gaviria, C. 2013. *Mitos o logos*, 131. Bogotá: Luna Libros, Editorial Universidad del Rosario.

Genes-Arrieta, F., A. Calle, J. C. Dávila, and L. D. Vélez. 2015. "Caracterización y evaluación de los agroecosistemas asociados a la producción especializada de leche en la Cuenca del Río Grande." In *Memorias del V Congreso Latinoamericano de Agroecología-SOCLA. Trabajos Cientificos*, edited by S. Sarandón, E. Abbona, 1230–1235. ISBN: 978-950-34-1265-7. Editorial Universidad Nacional de La Plata.

Gliessman, S. 1990. *Agroecology: Their role in the design of agricultural projects for the humid tropics*Race to save the tropics: ecology and economics for a sustainable future. G. E. J ed., En1990, 33–49 219 p. Washington, D.C, Island Press.

Gliessman, S., F. Risado, C. Guadarrama, J. Jedlicka, A. Cohn, V. E. Mendez, R. Cohen, L. Trujillo, C. Bacon, and R. Jaffe. 2007. Agroecología: promoviendo una transición hacia la sostenibilidad. *Ecosistemas* 16:13–23. http://www.revistaecosistemas.net/articulo.asp.

Gordon, C., R. Manson, J. Sundberg, and A. Cruz-Angón. 2007. Biodiversity, profitability, and vegetation structure in a Mexican coffee agroecosystem. *Agriculture, Ecosystems & Environment* 118:256–66 doi:10.1016/j.agee.2006.05.023.

Gorosito, I. L., M. Marziali, and M. Busch. 2018. Advantages of combining generalized linear models and occupancy models to find indicators of habitat selection: Small mammals in agroecosystems as a case study. *Ecological indicators* 85:1–10.

Guzmán, A., A. Link, J. A. Castillo, and J. E. Botero. 2016. Agroecosystems and primate conservation: Shade coffee as potential habitat for the conservation of Andean night monkeys in the northern Andes. *Basic and Applied Ecology* 17:1–10 doi:10.1016/j.agee.2015.09.002.

Hall, L., P. Krausman, and M. Morrison. 1997. The Habitat Concept and a Plea for Standard Terminology. *Wildlife Society Bulletin* 25:173–82.

Hart, R. 1985. *Conceptos básicos sobre agroecosistemas*, 159. San José, Costa Rica: IICA.

Hecht, S. 1999. "La evolución del pensamiento agroecológico." In Agroecología bases para una agricultura sostenible, edited by M. Altieri, 15–30. ISBN: 9974-42-052-0. Montevideo: Nordan Comunidad.

Hernández-Martínez, G., R. H. Manson, and A. Contreras. 2009. "Quantitative classification of coffee agroecosystems spanning a range of production intensities in central Veracruz, Mexico." *Agriculture, Ecosystems & Environment* 134: 89–98. doi:10.1016/j.agee.2009.05.020.

Holdridge, L. R. 1978. *Ecología basada en zonas de vida*, 216. San José, Costa Rica: IICA.

Honderich, T., and C. G. Trevijano. 2008. *Enciclopedia Oxford de Filosofía*, edited by T. Honderich, 2nd ed. ISBN: 978-84-309-4780-5. España: Editorial TECNOS.

Instituto de Recursos Mundiales. 2002. *Recursos mundiales. La Gente y los Ecosistemas: se deteriora el Tejido de la Vida. Programa de Naciones Unidas para el Desarrollo-Programa de*

Naciones Unidas para el Medio Ambiente–Banco Mundial–Instituto de Recursos Mundiales, 407. ISBN: 84-932176-1-1. Madrid: EcoEspaña Editorial.
Johansen, O. 2004a. *Anatomía de la empresa: una teoría general de las organizaciones sociales*, 241. México D.F: Limusa.
Johansen, O. 2004b. *Introducción a la teoría general de sistemas*, 168. México D.F: Editorial Limusa.
León, T. 2014. *IPerspectiva ambiental de la agroecología. La ciencia de los agroecosistemas*, 1st ed., 398. Bogotá: Universidad Nacional de Colombia.
Leonard, A. 2010. *La historia de las cosas: de cómo nuestra obsesión por las cosas está destruyendo el planeta, nuestras comunidades y nuestra salud. Y una visión del cambio*, 392. 1ª ed. ed.–Buenos Aires: Fondo de Cultura Económica.
León, T., T. Mendoza, and C. Córdoba. 2014. La estructura agroecológica principal de la finca (Eap): un nuevo concepto útil en agroecología. *Agroecología* 9:55–66.
Li, R., H. Lin, H. Niu, Y. Chen, S. Zhao, and L. Fan. 2019. Smallholder preference and agroecosystem service trade-offs: A case study in Xinzheng County, China. *Agricultural systems* 168:19–26. doi:10.1016/j.agsy.2018.10.002.
Madrid, J. H., M. Aguilar, V. L. D, and S. Muriel. 2017. Riesgo de pérdida de los sistemas de producción agrícola tradicional por la amenaza turística en Occidente Cercano (Antioquia, Colombia). *Revista Cuadernos de Geografía* 62. 309–25. DOI. doi:10.15446/rcdg.v26n2.59154.
Merlino, R., and M. Rabey. 1993. Resistencia y hegemonía: Cultos locales y religión centralizada en los Andes del Sur. *Sociedad y Religión* 10-11. 146–66. DOI. doi:10.36901/allpanchis.v24i40.799.
Murcia, C., J. Aronson, G. Kattan, D. Moreno, K. Dixon, and D. Simberloff. 2014. A critique of the ‘novel ecosystem’ concept. *Trends in Ecology & Evolution* 29 (10). doi: 10.1016/j.tree.2014.07.006.
Nava, R., R. Armijo, and J. Gastó. 1979. *Ecosistema. La unidad de la naturaleza y el hombre*, 330. México: Universidad Autónoma Agraria Antonio Navarro.
Navas, A., M. López-Vicente, L. Gaspar, L. Palazón, and L. Quijano. 2014. Establishing a tracer-based sediment budget to preserve wetlands in Mediterranean mountain agroecosystems (NE Spain. *The Science of the Total Environment* 496:132–43. doi:10.1016/j.scitotenv.2014.07.026.
Odum, E., and F. Sarmiento. 1998. *Ecología. El puente entre ciencia y sociedad*, 343. México D.F: McGraw Hill Interamericana.
O’neill, R. V., D. L. DeAngelis, J. B. Waide, and T. F. H. Allen. 1986. A hierarchical concept of ecosystems. *Monographs in Population Biology 23*. doi:10.1515/9780691236605.
Perfecto, I., and J. Vandermmer. 2015. Structural constraints on novel ecosystems emergence in agriculture: The rapid of stereotypic modules. *En: Perspectives in Plant Ecology, Evolution and Systematics* 17:522–30. doi:10.1016/j.ppees.2015.09.002.
Prigogine, I., and I. Y Stengers 1990. La nueva alianza. Metamorfosis de ciencia. Ed. E. S. A. Alianza, Madrid 359 pag.
Puan, C. L., A. W. Goldizen, M. Zakaria, and G. S. Baxter. 2011. Understanding of relationships between ground cover and rat abundances: An integrative approach for management of the oil palm agroecosystem. *Crop Protection* 30:1263–68. doi:10.1016/j.cropro.2011.05.025.
Putnam, H. 1984. El significado de “significado. *En: Teorema: Revista Internacional de Filosofía* 14:345–406.
Rao, C., K. Kareemulla, P. Krishnan, G. Murthy, P. Ramesh, P. Ananthan, and P. Joshi. 2019. Agro-ecosystem based sustainability indicators for climate resilient agriculture in India: A conceptual framework. *Ecological indicators* 105:621–33. doi:10.1016/j.ecolind.2018.06.038.
Ripoche, A., M. Crétenet, M. Corbeels, F. Affholder, K. Naudin, F. Sissoko, J. Douzet, and P. Tittonell. 2015. Cotton as an entry point for soil fertility maintenance and food crop

productivity in savannah agroecosystems “evidence from a long-term experiment in southern Mali. *Field Crops Research* 117:37–48. doi:10.1016/j.fcr.2015.02.013.
Sarabia, M., P. Cornejo, R. Azcón, Y. Carreón-Abud, and Larsen J. 2017. Mineral phosphorus fertilization modulates interactions between maize, rhizosphere yeasts and arbuscular mycorrhizal fungi. *Rhizosphere* 4:89–93. doi:10.1016/j.rhisph.2017.09.001.
Sarandón, S. 2014. “El agroecosistema: Un ecosistema modificado.“ In *Agroecología: bases teóricas para el diseño y manejo de agroecosistemas sustentables*, edited by S. Sarandon, and C. Flores, 1st ed. 100–130. ISBN: 978-950-34-1107-0. La Plata: Universidad de La Plata.
Saravia, A. 1985. *Un enfoque de sistemas para el desarrollo agrícola*, 265. San José, Costa Rica: IICA.
Schumacher, E. F. 1984. *Lo pequeño es hermoso*, 310. Madrid: Hermann Blume.
Tamayo, M. 2011. *El proceso de la investigación científica*, 444. 5ta. Edición ed. México: Limusa.
Toledo, V., and P. Moguel. 1992. Ecología, geografía y producción rural: El problema de la conceptualización de la naturaleza. *Relaciones* 12:7–22.
Tosi, J. 1972. *Una clasificación y metodología para la determinación y el levantamiento de mapas de la capacidad de uso mayor de la tierra. Proyecto UNDSP/SF-FAO. Col. 16 Universidad nacional de Colombia*, 45. San José, Costa Rica: C.C.T.
Valdés, N., D. Pérez, M. Márquez, L. Angarica, and D. Vargas. 2009. “Funcionamiento y balance energético en agroecosistemas diversos.“ *Cultivos Tropicales* 30: 36–42.
Vandermeer, J. 2011. *The ecology of agroecosystems*, 388. Sudbury, Maschutes: Jones and Bartlett Publishers.
Vélez, L. D. 2004. El paradigma científico de las ciencias agrarias: una reflexión. *Review Faculty Nacional de Agronomía Medellín* 57:2145–60.
Vélez, L. D., and J. Gastó. 1999. “Metodología y determinación de los estilos de agricultura en escala predial.“ *Ciencia e Investigación Agraria* 26: 75–100.
Vélez, L. D., and F. Leiva. 2017. “Ciencia, tecnología e innovación en el medio rural: Un aporte para la paz en Colombia.“ In *Territorio en vilo Desarrollo rural para el posconflicto*, edited by F.Leiva, ISBN: 978-958-775-890-0. Bogotá: Universidad Nacional de Colombia.
Vilaboa, J. A. 2013. “La ganadería doble propósito desde una visión Agroecosistémica.“ *Agroproductividad* 6: 9–15.
Xu, W., and J. Mage. 2001. A review of concepts and criteria for assessing agroecosystem health including a preliminary case study of southern Ontario. *Agriculture, ecosystems & environment* 83. 215–33. DOI. doi:10.1016/S0167-8809(00)00159-6.