Article

Bibliometric analysis of scientific knowledge on agroecosystem resilience

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Abstract

Global phenomena such as climate change threaten the resilience of agroecosystems and therefore food security. Thus, the objective of this paper was to analyze the cumulative nature and outstanding advances in the knowledge of the resilience of agroecosystems as a basis for the development of new trends in the subject. A literature review was conducted using the Web of Science database, considering criteria such as date of publication, disciplines and scientific journals. The search covers the period from 1993 to 2020. One hundred eighty-eight publications were identified, with 2018 and 2019 being the years with the highest number of articles published. The research areas with the most publications on resilience are ecology (71), agriculture (52) and environmental sciences (44). Regarding the connectivity based on the value of intermediate centrality, the areas of greatest interrelationship are mainly: agriculture (0.45), science and technology (0.28), environmental sciences (0.2) and ecology (0.12). In the dynamics and study of resilience, the adaptability of the agroecosystem stands out. The conceptual model of resilience analyzed facilitates its study and is composed of: precariousness, latitude, resistance and panarchy. Therefore, the indicators for quantifying resilience in agroecosystems are heterogeneous and multidimensional. It is concluded that resilience has been conceptually studied as an emerging property from the agroecological approach, recently from the socioecological systems approach, where adaptability and interdiscipline are highlighted as a means to solve complex problems.

Keywords: adaptation, regeneration, vulnerability.

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Introduction

From theory and conceptually, agroecosystems as units of study appear in academic discussions until the 70's of the last century addressing the interrelationship between agricultural systems and the human being (Harper, 1974; Argueta *et al*., 2015). Subsequently, in the 80s and 90s, studies on agroecosystems addressed the design of strategies for the sustainable management of natural resources (Conway, 1987) and it is from 2000, that the recurrence of climate change and other global threats began to be addressed with the application of integrative approaches to modeling and planning, taking up pro-environmentalist principles such as organic, peasant and indigenous agriculture (Gliessman, 2002; Casanova-Pérez *et al*., 2015; Mebarki, 2017).

Since the emergence of the agroecosystem concept construction, it has been approached with positivist-deterministic criteria (Maldonado and Gómez, 2011) and with a linear and simplified perspective. The reductionist approach to research in agroecosystems since its emergence as a concept was practically contrary to the nature of phenomena such as climate change that call into question predictability.

In this research, the study of the agroecosystem was approached as an allopoietic system with a complex network of interactions, and with adaptability of the socioecological type composed of social, economic, technological and environmental components, where their strength, the processing of signals and information and the capacity of adaptation provides resilience expressed as an emerging property to disturbances and panarchies of the sub and supra-system (Mitchell, 2009; Casanova-Pérez *et al*., 2015; Dekkers, 2015; Gao and Barabási, 2016).

It is common for agroecosystems to exhibit a significant cyclical behavior that occurs at multiple scales (Gunderson, 2008). To conceptualize the interaction of cross-scales, the dimensions of the agroecosystem can be represented in space and time, such is the case in the analysis of a geographical region, a farm system, agroecosystems with various crops and livestock, a crop or simply a plant or animal species (Hart, 1985; Dekkers, 2015).

Panarchy theory can describe the effect of small-scale indicators with their respective fast and short-duration expression, and their effect on a larger scale with a slow expression, but with longer duration. The effect of indicators can come from the micro or macrosystem influencing incremental changes that occur slowly as systems mature.

This will lead to an adaptive change that occurs after disturbances. Nevertheless, there is a risk of reaching the state of transformation that could occur if the resistance of the system is overcome by the disturbance, which will lead to the conduction of the agroecosystem to a new state with different types of structures, processes and controls (Gunderson, 2008).

Due to global challenges for humanity such as achieving food security under climate change, it is considered important to know the cumulative nature, the outstanding advances and the trend in the knowledge of the resilience of agroecosystems as a basis for the development of new trends in the subject.

So, this research starts from answering the following questions, what are the domains, origin of publications, authors, concepts, methodologies and theories for the study of resilience of the agroecosystem? what is the outlook for the resilience of agroecosystems? and aims to determine the cumulative nature and outstanding advances in the knowledge of the resilience of agroecosystems as bases for the development of new trends in the subject.

This article is divided into six parts: 1) studies on resilience in agroecosystems; 2) the conceptualization of resilience in the context of agroecosystems; 3) the components of resilience; (4) resilience indicators; 5) studies of the stages of resilience; and 6) the outlook of resilience analysis in agroecosystems.

Materials and methods

A literature review was conducted using the Web of Science database and criteria for words such as ‘resilience’ and its association with ‘agroecosystems’, ‘adaptation’, ‘agricultural systems’ and ‘agriculture’. Subsequently, the results were refined. Once the articles that address resilience as an emerging property of agroecosystems were identified, the concepts and methods for the analysis of resilience in agroecosystems were reviewed and identified. Next, the articles were quantified according to the year of publication.

Also, a database was organized in Txt format that included information by authors, topic, country of origin, and citations from the author. The CiteSpace 5.3 visual tool was used to analyze the frequency of citations and the most connected articles by co-citations of authors in the references of published articles were determined.

Similarly, the title, abstract and keywords were analyzed to identify trends and domain connections according to the resilience approach topics.

Results

Resilience studies on agroecosystems

In recent years, the term resilience has taken on importance and has been used in various fields of knowledge. In the case of agroecosystems and resilience (as keywords), there have been 188 publications since 1993, with 2018 and 2019 being the years with the most articles published with 30 and 32 articles respectively (Figure 1).

The articles on agroecosystem resilience analyzed based on their frequency of citations were integrated into 11 domains described below: environmental sciences and ecology (71), agriculture (52), environmental sciences (44), ecology (32), science and technology (26), multidisciplinary agriculture (23), green and sustainable science (20), environmental studies (19), biodiversity and conservation (10), soil science (9), agronomy (7), meteorology and atmospheric sciences (4), multidisciplinary science (3) and water resources, plant science, environmental engineering, biology, biomedicine, forestry and engineering with two publications respectively.

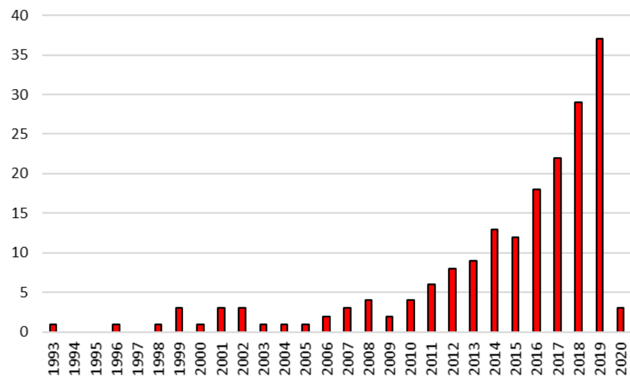

Figure 1. Publications on agroecosystem resilience registered on Web of Science from 1993 to 2020.

According to connectivity based on the intermediate centrality value, the areas that relate to others in greater frequency were mainly environmental sciences and ecology (0.37), agriculture (0.32), environmental studies (0.29), science and technology and other topics (0.27), ecology (0.2) and environmental science (0.14) (Figure 2). The marked relationship between the various areas presents interactions and feedbacks between social, economic, political and ecological problems different space-time scales (Castillo and Velázquez, 2015).

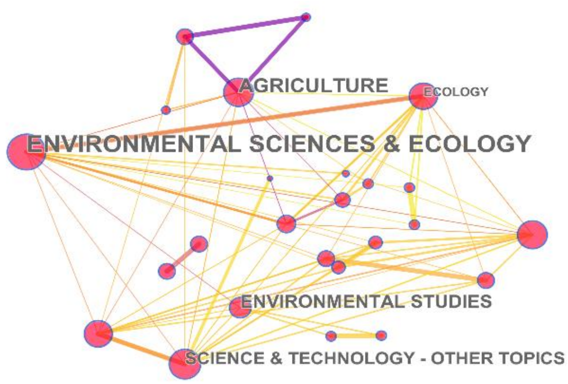

Figure 2. Main disciplines that address resilience in agroecosystems according to the CiteSpace tool.

Studies have shown that nodes with high intermediation centrality values tend to identify boundary expansion potentials that can lead to transformative discoveries.

The country of origin of the co-authors who have published on resilience are mainly from: United States of America (34), France (20), Australia (10), Canada (7) and Germany (6). With France and the United States of America being the nodes that connect and influence two or more large groups (Figure 3), this is indicated by the size of each node (Chaomei, 2014). The results shown in the networks show similarity in the domains analyzed by Hosseini *et al*., (2016), who, when conducting a literature review on systems resilience, determined the presence of Psychology as the main area and followed by environmental sciences and ecology as areas from which this concept has also been addressed.

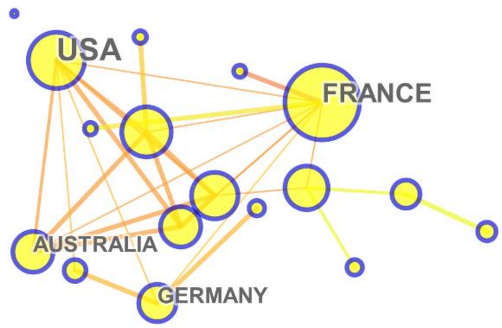

Figure 3. Main countries of origin and value of intermediate centrality of co-authors related to the publications of resilience of agroecosystems in the period 1993-2020.

In relation to the most frequently cited authors of the 188 articles, the next stand out: Altieri (53), Folke (31), Walker (30), Tilman (29), Holling (26), Gliessman (22), Gunderson (16), Kremen (15), Lal (15), Tscharntke (14), FAO (14), Scheffer (14), Lin (12), Carpenter (12), Adger (11), Van Der (11) and Perfecto (11). Regarding the centrality based on the connectivity of the authors through co-quotations, the next stand out mainly: Altieri (0.24), Hooper (0.20), Walker (0.21), Holling (0.12), Folke (0.11), Swift (0.11), Tilman (0.1), Tscharntke (0.08), Lin (0.06) and Koohafkan (0.06). Subsequently, other authors with a lower degree of centrality appeared and these are: Gliessman (0.04), Gunderson (0.04), Scheffer (0.03), FAO (0.03), Lal (0.02), Carpenter (0.02) and Kremen (0.01).

The intensity of the relationship of outstanding authors and those with a lower degree of centrality is due to the number of articles cited that have these authors in their references (Figure 4). In a broader context on resilience of systems, Hosseini *et al*. (2016) characterized the presence of authors who study resilience from qualitative, semiquantitative and quantitative approaches.

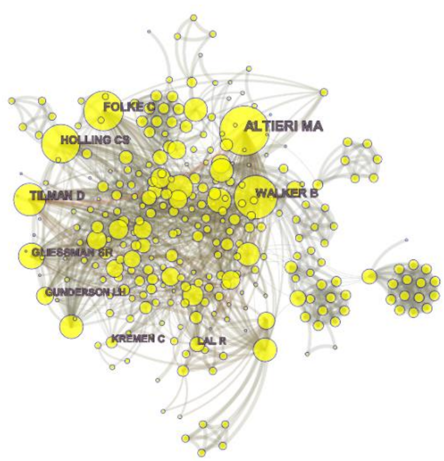

Figure 4. Network that shows the main authors cited in the 188 articles analyzed.

Of the total number of articles (188) for the period 1993-2020, and according to Web of Science, the articles most cited in the extensive database and without delimiting their relationship to agroecosystems, these are related to the study of the agroecosystem resilience from the ecological approach (Table 1).

Table 1. Main articles on resilience of agroecosystems cited.

Publication title	Authors	Total citations
Landscape perspectives on agricultural intensification and biodiversity - ecosystem service management	Tscharntke *et al*. (2005)	1915
Understanding relationships among multiple ecosystem services	Bennett *et al*. (2009)	846

Conceptualizing resilience in the context of agroecosystems

The word resilience comes from the Latin resillire that means to jump backwards and was initially used in the area of physics to describe the stability of materials and their resistance to external impacts (Holling, 1973; Reid and Boterill, 2013). In the 60's with the growth of system thinking, the concept was used in ecology (Reid and Boterill, 2013) and its definition highlights two aspects; the first, about the recovery and return to the initial state of the ecosystem after an impact and the second, about how a system has been disturbed and remains without changing its function (Bodin and Wilman, 2004; Masterson *et al*., 2014).

Subsequently, the concept was incorporated into agroecosystems and in the late 80's and 90's, it was applied within the ecological theoretical framework, particularly taking the foundations of the concept of Holling (1973). Returning to the analysis of networks in Figure 4 and based on definitions of the authors with greater centrality, two types of approaches to the study of resilience were identified: an agroecological approach and another approach to socioecological systems.

From agroecology and with the aim of developing sustainable agroecosystems with less environmental impact, highly productive and economically viable, emphasis was placed on resilience as an emerging property of the agroecosystem based on principles such as productivity, stability, sustainability, equity and ecological principles (Conway, 1987; Thomas and Kevan, 1993; Gallopín, 1995).

In addition to the above, resilience was conceptualized as an attribute of the health of the agroecosystem and was also studied from the relationship with sustainable practices, environmental services and biodiversity (Okey, 1996; Altieri 1999; Tscharntke *et al*., 2005). The author Walker (2004) integrated into the study of resilience the concept of socioecological systems, which extrapolated to agroecosystems integrates the emerging properties of the producer in their interaction with elements of adjacent systems.

The concept of socioecological systems highlights cyclical adaptability as the ability of the elements of the agroecosystem to influence resilience through constant feedback that leads to building collective structures (based on feedback) that increase their resistance and probability of recovery from disturbances, thus generating more information that is incorporated back into the elements of the system (Davoudi, 2012; Titonell, 2013).

However, the macro and microsystem are also considered, because in them there may be variables conductive to events of drastic disturbance that could exceed the resistance of the agroecosystem, avoiding the emergence of resilience and instead, a transformation scenario appears (Walker, 2004; Folke, 2006; Gunderson, 2008; Folke *et al*., 2010; Folke, 2016).

The extension of notions of resilience in society has important limits, particularly its conceptualization of social change. This is due to the lack of attention to normative and epistemological problems that underlie the notion of social resilience.

So, the role of knowledge at the intersections between environmental and social dynamics helps to address normative issues and their respective values as an integral part of the development and functioning of the socioecological system. Therefore, it is necessary to develop methods of sociology that permit to strengthen the study of human beings in relation to their behavior under stress scenarios caused by external phenomena (Cóte, 2011).

It is likely that unified methods for the study of resilience in agroecosystems are not yet defined. This coincides with a series of definitions on the resilience of agroecosystems and with proposals for variables with which this phenomenon could be addressed.

Components of resilience

The definition of resilience is confusing because of the disciplinary connotations in which it has been used. From a socioecological systems approach, resilience is a component of the agroecosystem trajectory (Figure 5) and is operationalized with four components proposed by Walker *et al*. (2004): latitude. It is defined as the maximum amount that can be changed to the system before losing its recoverability. Basically, it is the width of the basin of attraction. A wide basin means that the system can experience a greater number of states without reaching the transformation, resistance. It is the ease or difficulty to change the system.

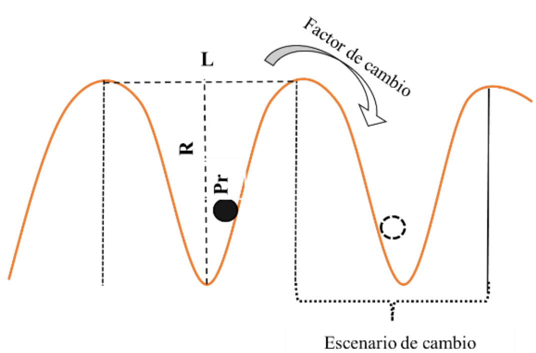

Figure 5. Limits of a socioecological system to express resilience, where: L= means length, R= resistance and Pr= precariousness (Walker *et al*., 2004).

It is related to the topology of the basin. Deep basins of attraction indicate that greater forces or disturbances are required to change the current state to another, precariousness. It is the current trajectory of the system, which places it with respect to a limit or 'threshold' that, if exceeded, hinders or makes it impossible to recover (Pr), panarchy. Process of influence on the system caused by the states and dynamics of the (sub) systems at scales above and below the scale of interest (Pa), (Walker *et al*., 2004).

In the community context, Masterson *et al*. (2014) propose three dimensions within the resilience process: 1) resistance or robustness is the ability of the capital system to absorb, change or resist the impacts of natural phenomena, which implies a reduction in probabilities of system failures; 2) dimension called speed refers to the recovery path and the speed with which the system recovers its pre-impact state; and 3) the third refers to increasing resilience through learning or adaptability.

Twigg (2007) proposes various dimensions or components for social systems (governance, risk assessment, knowledge and education, risk management and vulnerability reduction, disaster preparedness and response) that a community must assemble to increase its resilience, prioritizing strategies that enable systems to act on their own and strengthen their capacities rather than focusing on their vulnerability to disaster or their needs in an emergency.

From a social perspective, the sustainability and resilience of a community depend on its ability to access and make the best use of its economic, political and civil capital in the face of a disturbance (Akter and Mallick, 2013). Other important factors in the dimensions of resilience are: autonomy, food security, adequate levels of nutrition, health and education to name a few, as well as the versatility of modifying the structure of their system as required in disaster scenarios (De La Fuente, 2016).

Resilience indicators

Any resilience study must undoubtedly start from the questions, what makes an agroecosystem resilient? what are those attributes of the system that give it greater or lesser resilience? and what indicators are intrinsic and extrinsic to the agroecosystem? However, there is likely to be confusion about what aspect of resilience is being measured and what kind of indicators are being considered, since resilience may occur in a later period of time or on a particular scale at the expense of the resilience of the system.

To avoid such confusion, it is important to be clear about the scale and period of time in which the study of resilience is approached (Carpenter *et al*., 2001; Hernández *et al*., 2002). To facilitate the analysis, the outstanding indicators presented in different studies were grouped into seven categories: socioecological systems (Cabell and Oelofse, 2012), agroecological systems (Bruneau *et al*., 2003; Altieri and Nicholls, 2012; Altieri and Nicholls, 2015), social systems (Rose, 2007; Rose, 2009; Cabell and Oelofse, 2012; CENAPRED, 2015; Hosseini *et al*., 2016), community capacities (Rose, 2007; Masterson *et al*., 2014; CENAPRED, 2015; Qasim, 2016), economic capacities (Rose, 2007; Rose, 2009), institutional capacities (Rose, 2007; CENAPRED, 2015; Qasim *et al*., 2016) and infrastructure capacities (Rose, 2007; CENAPRED, 2015; Qasim *et al*., 2016).

Each category relates to the agroecosystem directly or indirectly and its influence determines the response of the agroecosystem to a crisis. Finally, once the resilience indicators have been selected, it is important to standardize the values obtained for which use can be made of equation (1) proposed by Hahn *et al*. (2009): $I_v=\frac{I_a-I_{min}}{I_{max}-I_{min}}$ 1), where I_v= is the standardized value of the indicator, I_a= is the value for a particular agroecosystem, I_{min}= for the minimum value of total agroecosystems, I_{max}= for the maximum value of total agroecosystems (Hahn *et al*., 2009).

In terms of disaster prevention, it is substantial to focus on increasing the robustness of the agroecosystem and decreasing vulnerability, because these variables are inversely proportional to resilience. An agroecosystem with low vulnerability might probably suffer no or minimal damage.

In the study and design of resilient agroecosystems, it is important to approach allopoietic processes to know how the dynamics of interaction with the environment or external systems are as promoters of changes in the state of the system or internal self-organization.

In the adaptation stage (prior to the expression of resilience), the agroecosystem modifies or changes some elements of its structure in response to the environment around it, so every time this phase ends and an agroecosystem is resilient, it can mean three things: 1) that the agroecosystem presents an internal self-organization; 2) that resilience is an emerging behavior; and 3) that it is a change of state resulting from an agroecosystem with high entropy (Dekkers, 2015). Finally, interdiscipline should be promoted as a methodological tool to address resilience.

This represents a common conceptual and methodological framework, derived from a shared conception of the science-society relationship, which will permit defining the problem to be studied under the same approach, without neglecting the specialization of each of the members of the research team (García, 2006).

Conclusions

The study of resilience as an emerging property in agroecosystems has increased significantly in the last ten years. The main domains in which the publications are grouped are: environmental sciences, ecology and agronomy. The authors of publications such as Altieri, Walker and Folke are the ones who presented the most co-citations so they can be considered as the main authors with influence on the subject. Today, socioecology has integrated the fundamentals of agroecology and social and economic disciplines to study resilience.

The current challenge is to analyze the resilience of the agroecosystem by reinforcing studies on qualitative social elements in relation to adaptability and learning in the context of space and time. The definition of resilience has evolved and will continue increasing in complexity as more elements are incorporated into it. Also, it is necessary to unify a method for all dimensions related to the resilience of the agroecosystem. System theory facilitates the study of the resilience of the agroecosystem and the most outstanding conceptual tool for its study is interdiscipline because it considers the elements of a system as inter-defined and in common conception on the general problem to be studied.

The more vulnerable an agroecosystem is, the greater the damage to its structure will be and therefore recovery will take longer, but also if the disturbance exceeds the resistance threshold of the agroecosystem, it will be transformed.

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