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Theoretical framework and methods for the analysis of the adoption-diffusion of innovations in agriculture: a bibliometric review

Marco teórico y métodos para el análisis de la adopción-difusión de innovaciones en la agricultura: una revisión bibliométrica

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Abstract

The adoption and diffusion of innovations are essential for both the development of production processes and the improvement of agricultural environmental sustainability, at any stage of the value chain. In recent years, social scientists have studied the diffusion and adoption of agricultural innovations from different approaches, such as innovation diffusion theory, behavioral models, econometric models, social capital and social network analysis, among others. In this study we analyze the scientific literature through a bibliometric analysis based on co-citation networks, to explore the theoretical pillars and bibliographic coupling, with which we explore the current methodological research trends of the last 50 years. The conclusions drawn from this

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analysis are that in recent years agricultural researchers on adoption and diffusion have designed multivariate methods that combine diverse study approaches. This review contributes to a better understanding of theory and practice in the study of the adoption and diffusion of agricultural innovations.

Key words: literature review; bibliometric coupling; co-citation analysis; innovation adoption; currents methods.

Resumen

La adopción y difusión de innovaciones son esenciales tanto para el desarrollo de los procesos de producción como para la mejora de la sostenibilidad medioambiental agrícola, en cualquier etapa de la cadena de valor. En los últimos años, los científicos sociales han estudiado la difusión y adopción de innovaciones agrícolas desde diferentes enfoques, como la teoría de la difusión de la innovación, los modelos de comportamiento, los modelos econométricos, el capital social y el análisis de redes sociales, entre otros. En este estudio analizamos la literatura científica a través un análisis bibliométrico basado en las redes de co-citación, para explorar los pilares teóricos y el acoplamiento bibliográfico, con el que exploramos las tendencias metodológicas actuales de investigación de los últimos 50 años. Las conclusiones que se derivan de este análisis son que en los últimos años los investigadores agrícolas sobre adopción y difusión han diseñado métodos multivariantes que combinan diversos enfoques de estudio. Esta revisión contribuye a un mejor entendimiento de la teoría y práctica en el estudio de la adopción y difusión de innovaciones agrícolas.

Palabras clave: revisión bibliográfica; acoplamiento bibliométrico; análisis de co-citación adopción innovaciones; corrientes metodológicas.

1 Introduction

Different types of innovations are implicit in many of the processes involved in agricultural activities (Campos, 2021; Feder et al., 1985; Morgan & Murdoch, 2000; Ruttan, 1996). These range from the adoption of traditional innovations to complex technical innovations (Kabunga et al., 2012; Moglia et al., 2018). Many of the innovations affect a large number of sectors and sub-sectors of the value chain that are key to agricultural development, such as the adoption of agricultural technologies and inputs, or innovations of a structural nature, such as new forms of organization and cooperation (Feder et al., 1985; Hannus & Sauer, 2021; Hasler et al., 2016).

In a broader sense, diffusion and adoption of innovations are often used together, although they are different concepts. Hence, diffusion of innovations refers to the process by which an innovation is communicated through certain channels in a given time among the members of a social system (Rogers, 2003). The concept of adoption refers to the acceptance (or rejection) of innovations, whether by individuals or by organizations (Kee, 2017). However, since adoption already implies diffusion, here we will use the global term diffusion and adoption of innovations, with particular reference to their application to agriculture. Much of the literature confirms that the adoption and diffusion of innovations in agriculture contributes to both economic and environmental sustainability competitive advantages (Aguilar-Gallegos et al., 2015; Feder et al., 2004; Sharp & Hinrichs, 2001; Vollaro et al., 2019).

Social scientists have long been aware of the presence of processes of adoption and diffusion of innovations in relation to both agricultural practices and the use of different and changing technologies, either by individuals or by certain social groups. From this arose the need to develop sufficiently robust theories to adequately conceptualize such processes (Davis et al., 1989; Fishbein & Ajzen, 1975; Rogers, 2003; Venkatesh et al., 2003). Interpretive models (largely based on measures of statistical dispersion, such as variance) were also developed.

Traditionally, these investigations have been carried out by means of variance-based models and process with certain limitations, such as those related to the understanding of human behavior (Gruber, 2020). Critics of diffusion theory have suggested a multilevel framework with the need to incorporate other variables such as geographical (spatial and temporal diffusion), behavioral (relative advantage, uncertainty, risk aversion, etc.) or knowledge (Ruttan, 1996).

For years the agricultural sector has received a considerable amount of interest from scholars of the adoption and diffusion of innovations. Rural sociologists introduced the paradigm of diffusion of innovations by studying the influence of the introduction of hybrid corn seeds (Ryan & Gross, 1950, 1943). This type of research spread among rural sociologists between 1950 and 1960 and later expanded to interdisciplinary fields of diffusion (Valente & Rogers, 1995), increasing notably during the Green Revolution, where there was a boom in research on the process of adoption and diffusion of innovations. During this process, a large number of these studies focused on developing countries (Feder & Umali, 1993; Lawrence, 1988).

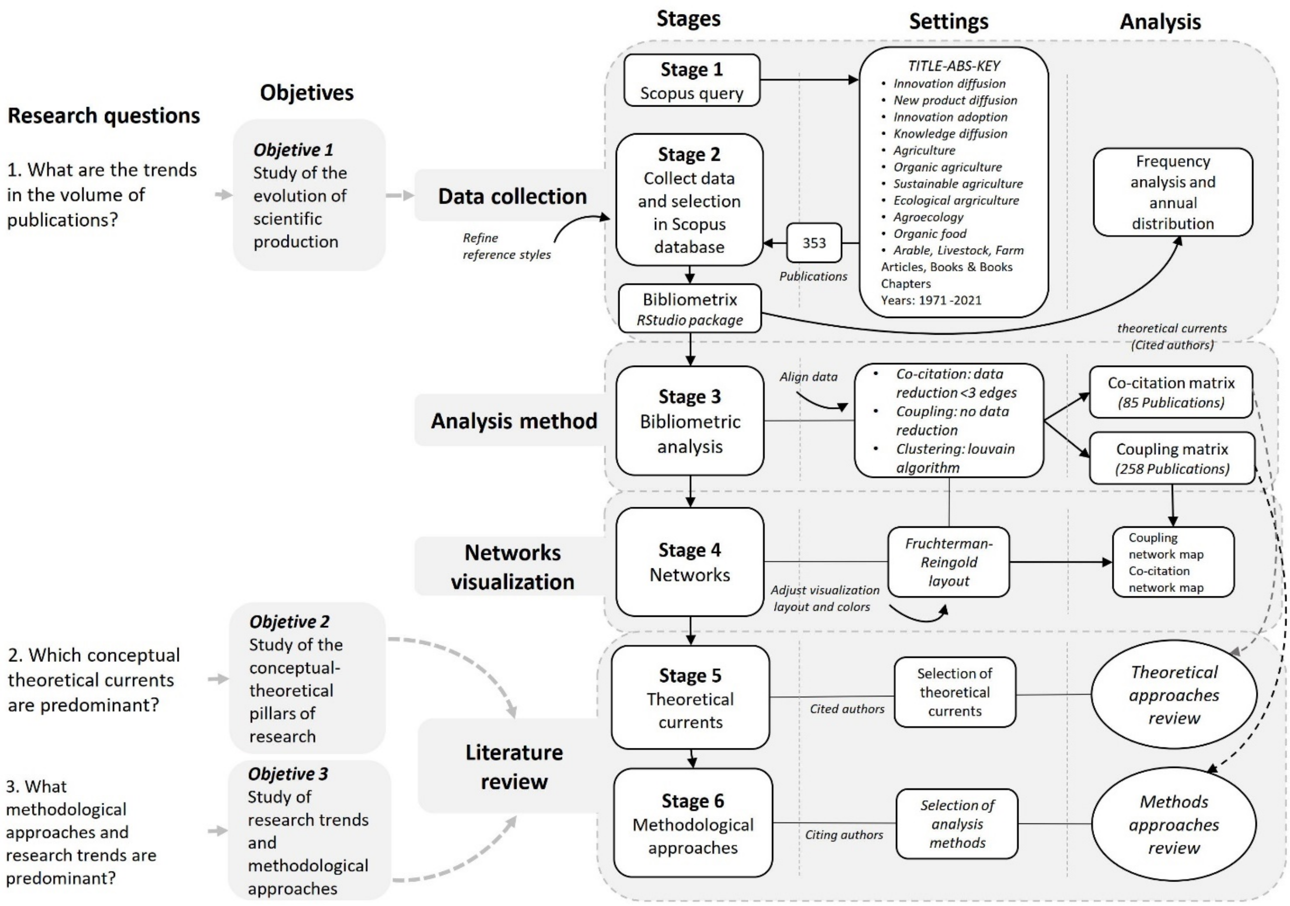
Initial bibliographical reviews on the theory of the diffusion of innovations revealed that by 1960 there were already about 500 publications and that in 1973, research on the diffusion of innovations numbered 1.417. In 1981 the total amount reached 3.085 publications. With regard to the link between rural sociology, agriculture and the study of the diffusion of innovations, during the 1950s, in the United States, there was a real increase in publications related to this topic (Rogers, 2003; Valente & Rogers, 1995).

Innovation adoption processes have been reviewed broadly in order to identify theoretical underpinnings, illustrating research trends, but without putting the focus on a particular large field of study (Li & Sui, 2011; van Oorschot et al., 2018). Similarly, systematic literature reviews through meta-analysis have succeeded in bringing clarity to a wide variety of key aspects such as attributes in the adoption of innovations (Kapoor et al., 2014b, 2014a). Thus, through literature reviews, models and conceptual frameworks have been proposed to guide development strategies, both focused on the adoption of innovations in organizations (Vagnani et al., 2019), as well as reviews of the limitations in the diffusion of innovations in disciplines such as marketing and sociological research (MacVaugh & Schiavone, 2010).

Given the interest in understanding the processes of diffusion in agriculture, literature reviews have been conducted where the importance of further agricultural research is noted, to understand the constraints, the importance of appropriate public policies and the question of whether technologies are adopted individually or in packages following a combined sequence, which would also need further research (Feder & Umali, 1993).

Considering the foregoing, the general aim of this study is to carry out a bibliometric review of two major combined fields, adoption and diffusion of innovations and agriculture. This general goal is broken down into three specific objectives; 1) to review scientific output; 2) to identify theoretical foundations through the bibliographic co-citation network; 3) to identify current research trends through the bibliographic coupling network and the methodological review of research trends. Therefore, the aim is to produce a synthesis document that brings together all these aspects in relation to the diffusion of innovations in agriculture. There are three research questions to which all this is intended to provide answers: 1) What have been or are the trends in relation to the volume of publications?; 2) What are the dominant theoretical and conceptual currents in the study of the diffusion of innovations in agriculture?; and 3) What types of methodologies are used and are most frequent in the applied and practical study of the processes of diffusion of innovations in agriculture? Figure 1 below presents an outline of the logical sequence of the research process, connecting the research questions with the objectives and the phases of the analysis process.

Figure 1. Description of bibliometric review process connecting with research questions and objectives



Source: authors' own elaboration

To focus the analysis, we compared results in the two main indexing database sources, Scopus and the Web of Science (WoS) databases. In both sources, we worked with an initial set of keywords, with individualized searches on publication titles, abstracts and keywords. For this first "coarse" analysis, publications in the form of articles, books, proceedings, etc. were included. Table 1 shows the obtained results (we have only worked with keywords in English, since the results in Spanish were comparatively very poor, and locating and defining the schools or authors that publish in Spanish on the diffusion of innovations in agriculture is not part of the objectives of this work).

The results shown in Table 1 are divided into two blocks. The first includes the four most important keywords related to the concept of "diffusion of innovations", which is very common in social science publications. The second part includes a total of 10 keywords, some very generic (such as agriculture or livestock) but others more specific, mainly related to the orientation towards organic and sustainable production. In this second block, innovation issues are very present, but not explicitly "diffusion of innovations" as such. These are publications much more in the field of sciences (agronomy, biology, etc.), very much oriented towards Science Citation Index (WoS) journals. This explains why these keywords are more abundant in the titles of these publications. This occurs, however, only in the titles, because again, both in the abstracts and in the keywords, the sources contained in Scopus show clearly higher frequencies.

It is clear that the selection of one or other database conditions the results. In addition to the higher frequency of keywords in the publications collected by Scopus, one fact seems to us to be particularly significant. The concept of "diffusion of innovations", which is key to our research, appears much more frequently among the keywords in Scopus than in WoS. Furthermore, if we go into more detail, the presence of "diffusion of innovations" in social science publications in Scopus alone accounts for more than 2.5 times the total number of references in all WoS databases that include this keyword (and much more if only the publications contained in the WoS Social Sciences Citation Index are counted).

Consequently, working with WoS would mean significantly restricting the universe of analysis, which would be a serious problem in a bibliometric study such as this one (for example, WoS might not highlight schools that work on the diffusion of innovations and that might be on the fringes of the more central schools). For all these reasons, in this research it has been decided to work with the Scopus database.

After database selection, the basis of this analysis is the selection of a whole series of research papers (in the form of articles, books and book chapters), for which keywords related to the two main combined fields mentioned, diffusion of innovations and agriculture, were used. The search was based on Web of Science (WoS) databases and, above all, on Scopus, which allows a longer period of 50 years (1971-2021). The result was the initial selection of 353 publications particularly relevant to the diffusion of innovations in agriculture.

The first research question refers to trends in the volume of publications, meaning how scientific production on the diffusion of innovations in agriculture has evolved over the last five decades. To this end, we focused, initially, on the analysis of the frequency of publications per year and, secondly, on a follow-up of the 10 most cited documents, those which, according to the bibliography, can be considered the most relevant (section 2). The second research question is aimed at detecting the dominant theoretical-conceptual currents in the study of the diffusion of innovations in agriculture. Two powerful tools of bibliometric analysis (Aria et al., 2020) are used for this purpose. The first is co-citation networks, which reflect the connections between the authors cited in the selected articles (section 3), while the second is based on bibliographic coupling network analysis, which measures the overlap of the selected articles (section 4). Bibliographic coupling is a type of analysis that also makes it possible to answer the third research question, based on defining which methodologies and themes or approaches are most commonly used in studies on the diffusion of innovations in agriculture (section 4).

Table 1. Number of references reported by keywords searches[1]

Syntax	Title			Abstract			Key words		
Social Sciences side	WoS	Scopus	Scopus / WoS	WoS	Scopus	Scopus / WoS	WoS	Scopus	Scopus / WoS
"Diffusion of innovations"	390	779	100%	1,435	4,148	189%	848	19,618	2,213%
"Innovation adoption"	318	406	28%	943	1,045	11%	571	929	63%
"Knowledge diffusion"	358	374	4%	909	1,045	15%	404	625	55%
"New product diffusion"	76	76	0%	105	140	33%	63	88	40%
"Difusión de innovac*"	11	10	-9%	30	0	-100%	43	0	-100%
"Difusión de conocimiento*"	4	3	-25%	52	2	-96%	8	0	-100%
Average			16%			9%			362%
Natural Sciences side	WoS	Scopus	Scopus / WoS	WoS	Scopus	Scopus / WoS	WoS	Scopus	Scopus / WoS
"Agriculture"	97,949	49,383	-50%	254,434	235,106	-8%	55,947	222,591	298%
"livestock"	28,475	17,001	-40%	98,441	83,384	-15%	13,524	37,688	179%
"Organic agriculture"	831	739	-11%	2,316	2471	7%	1,605	2,594	62%
"Sustainable agriculture"	4,752	2,700	-43%	7,814	8,930	14%	4,450	7,788	75%
"ecologic* agriculture"	158	130	-18%	533	555	4%	225	220	-2%
"Organic farming"	2,044	1,946	-5%	5,949	6,282	6%	3,355	7,839	134%
"agroecology"	946	739	-22%	1,541	1,701	10%	3,045	3,959	30%
"Sustainable farm*"	306	303	-1%	1,254	1,428	14%	266	437	64%
"Ecological farm*"	102	90	-12%	375	359	-4%	112	111	-1%
"Organic* food"	1,233	1,469	19%	2,634	3,267	24%	1,182	2,472	109%
Average			-18%			5%			95%

Source: authors' own elaboration

1 For the purpose only of this table, the searches have been updated both in WoS and Scopus on October 27th, 2022.

2 Data and methods

2.1 Data

As noted in the previous section, three types of analysis techniques are used to study the diffusion of innovations in agriculture. The first is the frequency of appearance of research (and its distribution over the period of the last 50 years). Second, co-citation networks between the relevant authors. This approach reveals the degree of connection between cited authors and facilitates the identification of conceptual theoretical pillars. And third, bibliographic coupling, whose analysis allows us to know the current research trends based on the degree of connection between the citing authors. The aim is to study the evolution of scientific production, the theoretical-conceptual pillars on which this type of studies are based, and the predominant methodological approaches and research trends.

The first step in obtaining the information that will form the basis of the study was to locate and perform a general review of the literature on the diffusion of innovations. This was done using different keywords, some as obvious as "diffusion of innovations", but also other words associated with the concept, such as "knowledge transfer", or "adoption of innovations". The Web of Science (WoS) and, above all, Scopus databases were used. Without applying year restrictions, and only with the keywords "innovation diffusion" or "innovation adoption" (either in the title, abstract or keywords), 4,678 documents were obtained (including articles, books, book chapters, conferences, etc.). If the term "agriculture" is added, the number of documents is reduced to 468. The aim is to obtain a solid picture of the scientific contributions on the subject.

Therefore, as a second step, the previous search has been completed with a more precise syntax. We have worked exclusively with the Scopus database, which facilitates the download of the bibliographic references with all the metadata, and we have also maintained the searches indistinctly in "title, abstract and keywords" of each document (article, book and book chapter). Here, however, the search terms have been expanded, not only by entering associated terms, but also by using the asterisk (*) function to detect small variations of keywords: (TITLE-ABS-KEY ("Innovation* Diffusion*" OR "innovation* of diffusion*" OR "new* product* diffusion*" OR "innovation* adoption" OR "knowledge diffusion*" OR "difusi* de innovaci*" OR "difusi* de conocimiento*") AND TITLE-ABS-KEY (agricultur* OR "organic* agriculture" OR "sustainable agricultur*" OR "ecologic* agriculture" OR farm* OR "organic farm*" OR "sustainable farm*" OR "ecological farm*" OR agroecolog* OR "organic* food" OR "arable" OR "livestock" OR "arable" OR "farm*".

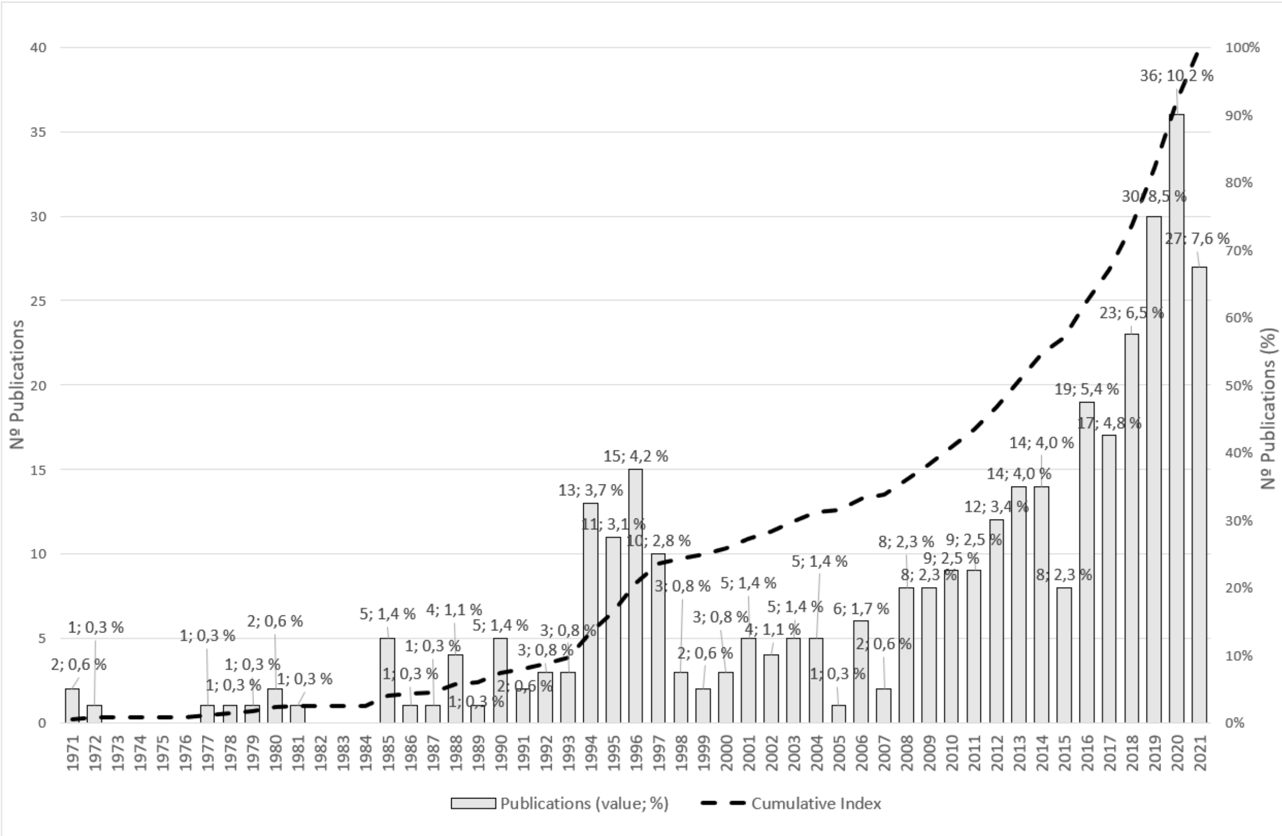
The result was 353 publications, with more than 15,000 citations. Of these publications, 339 are articles, 2 are books and 12 are book chapters, between 1971 and 2021, from 223 different sources (Table 2). The overall data show that these are relevant documents for the scientific community, with significant average values in terms of citations per year and per document. In terms of temporal evolution, after a boom period in the mid-1990s and a subsequent slowdown, it is in the last 15 years that research on the diffusion and adoption of innovations in agriculture has experienced a particularly significant increase in the number of relevant contributions (Figure 2).

Table 2. Main information about the references collection

Description		Results
Main information about data	Timespan	1971- 2021
	Sources (Journals, Books, etc.)	223
	Average years from publication	12.9
	Average citations per documents	14.7
	Average citations per year per document	1.33
	References	15,178
	Article	339
	Book	2
	Book chapter	12
	Total documents	353
Document contents	Keywords Plus (Scopus Keywords)	1,293
	Author's Keywords (DE)	986
Authors	Authors	938
	Authors of single-authored documents	68
	Authors of multi-authored documents	870
Authors collaboration	Single-authored documents	75
	Documents per Author	0.376
	Authors per Document	2.66
	Co-Authors per Documents	2.94
	Collaboration Index	3.13

Source: authors' own elaboration

Figure 2. Evolution of number of scientific documents



Source: authors' own elaboration

The most cited publications provide a first and fairly accurate overview of research trends (Table 3). As the titles and keywords highlight, the research trends include a variety of topics related to the processes of adoption and diffusion of innovations in agriculture. As would seem logical, there is a variety of research that specifically explores such processes in developing countries (Feder et al., 2004; Fischer & Qaim, 2012), while others focus on barriers to technology adoption (Long et al., 2016; Nkonya et al., 1997). However, the most frequent themes are related to the adoption of sustainable practices, such as agricultural conservation, sustainable agriculture, organic agriculture, soil conservation or carbon emissions, among others (D'Emden et al., 2006; Dimara & Skuras, 2003; Hassanein & Kloppenburg J.R., 1995; Long et al., 2016; Nkonya et al., 1997; Waheed et al., 2018).

In addition to keyword-based searches, the third approach used for this analysis was based on "bibliometrix" package developed for the RStudio statistical software (Aria & Cuccurullo, 2017). This tool allows, among other types of analysis, bibliographic mapping (bibliographic linking and co-citation networks) to analyze the scientific landscape in any field of study (Aria et al., 2020, 2022).

Table 3. Most global 10 cited documents (based on Scopus)

	Paper	Title	Total Citations	Total citations per year
1	Fischer & Qaim (2012)	Linking Smallholders to Markets: Determinants and Impacts of Farmer Collective Action in Kenya	279	25
2	Edwards-Jones (2006)	Modeling farmer decision-making: concepts, progress, and challenges	211	12
3	Adrian, Norwood & Mask (2005)	Producers' perceptions and attitudes toward precision agriculture technologies	144	8
4	Long et al. (2016)	Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland, and Italy	142	20
5	Feder et al. (2004)	The acquisition and diffusion of knowledge: the case of pest management training in farmer field schools, Indonesia	141	7
6	Nkonya et al. (1997)	Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy	122	5
7	Waheed et al. (2018)	Forest, agriculture, renewable energy, and CO2 emission	112	22
8	Chen & Song (2008)	Efficiency and technology gap in China's agriculture: A regional meta-frontier analysis	91	7
9	D'Emden et al. (2006)	Adoption of conservation tillage in Australian cropping regions: An application of duration analysis	86	5
10	Yifu (1991)	Education and Innovation Adoption in Agriculture: Evidence from Hybrid Rice in China	84	3

Source: authors' own elaboration

Fourthly, for both the analysis of bibliographic coupling and that of co-citation networks, the requirement of a minimum connection of 3 axes per node has been maintained. Hence, the network is simplified, leaving those with a much more relevant role. This adjustment has made it possible to reduce the co-citation network to 85 nodes, while the coupling network has been reduced to 258 nodes. On the other hand, we work with the degree centrality, reflected in the size of each node. The degree centrality is a standard measure widely used in bibliometric analyses and characteristic of Social Network Analysis (Aria et al., 2020; García Hernández, 2013; van Oorschot et al., 2018; Wasserman & Faust, 1994), which allows visualizing the most active network nodes through the connections in the adjacency matrix. In this particular case, the degree of centrality refers to the connections between nodes in the bibliographic network.

Different methods can be used to detect and define multiple communities in a network. Although experts differentiate between community detection and cluster analysis, for practical purposes these two approaches are similar and, for our objectives, it is not necessary to go into their specificities. Here we will work with the first approach, community detection, which is used to analyze networks that depend on a simple attribute which, in our case, would be the links between authors. In turn, within this approach there are various methods, among which the Louvain algorithm (Blondel et al., 2008) stands out, based on the gain of modularity (cohesion in the network), that is, on the definition or delimitation of communities that are made as cohesive as possible. For practical purposes, the algorithm, through multiple iterations, builds communities or clusters with the maximum cohesion that can be obtained from the given initial relationships. The algorithm is especially powerful for bibliometric analysis through citation networks, as highlighted in recent studies (Mejia et al., 2021). For all these reasons, this is the approach chosen in our research. In addition, we will use the most popular term "cluster" to refer the resulting communities from the application of this algorithm.

Considering the above, in order to obtain clusters we have relied on the "Louvain" algorithm, opting for a Fruchterman-based visualization, following the steps of previous studies performed with bibliometrix package (Aria & Cuccurullo, 2017). This type of algorithm and visualization layer positions the nodes with more connections in the center, while the distance between them indicates the proximity in the subject matter in the research field (Aria & Cuccurullo, 2017; Aria et al., 2020; Lancichinetti & Fortunato, 2009). Moreover, in the bibliographic coupling network, and for each of the clusters, the standard deviation of the degree centrality is used, with which we have an indicator of the degree of dispersion of the nodes in the network (O'Malley & Marsden, 2008; Valente et al., 2008). These adjustments make it possible to differentiate and give greater visibility to references with a greater number of connections in the bibliographic coupling network.

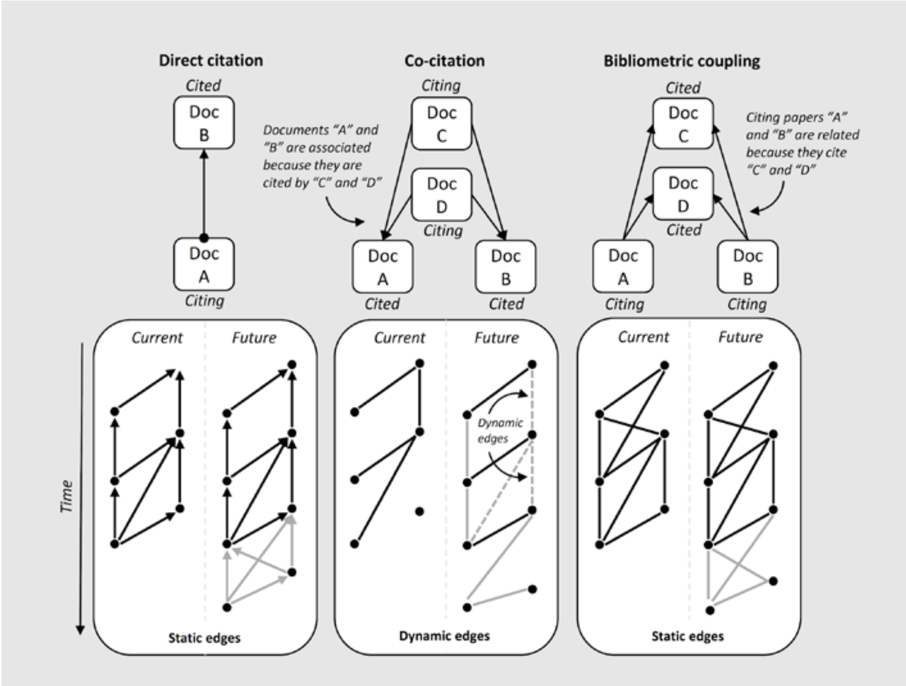
Finally, it should not be forgotten that bibliometric analyses face different limitations, especially bias limitations, at different stages (Gureyev & Mazov, 2022). Therefore, to minimize the effects of such limitations, firstly, a properly constructed syntax, which is adapted to our case study and allows reducing noise and false positives, is essential. Secondly, the bibliometric analysis must go through a process of reviewing the references of the selected documents to avoid, for example, duplicities or missing citations, derived from the fact that the same reference has been recorded in different styles. Third, as highlighted in several studies (Linnenluecke et al., 2019; Onwuegbuzie & Frels, 2016), bibliometric analysis cannot replace a comprehensive literature review, or an in-depth meta-analysis, due to the large volume of information generated. Accordingly, one of the avenues that can be employed to reduce this information gap is to perform a detailed document analysis (van Oorschot et al., 2018). In doing so, the review, in addition to allowing the identification of theoretical-conceptual pillars and research trends, provides insight into methodologies of analysis (see Section 2.3 Methodological review of research trends).

2.2 Methods: direct citations, co-citation networks and bibliographic coupling

Bibliometrics or scientometrics often focuses on the investigation of the metadata contained in scientific references. This concerns the investigation of the properties of the publication system, who publishes and with whom, where it is published and to which area it belongs (Jarden et al., 2019; Nakagawa et al., 2019). The bibliometric review of the scientific literature allows us to obtain a relatively accurate picture and, in any case, sufficient to adequately assess the development of research on the topic in question. It also provides us with a high degree of accuracy about the various methods of analysis used and, if necessary, would allow us to reconsider and develop new methodological approaches (Petticrew & Roberts, 2008). Thus, two approaches are mainly used in bibliometrics, 1) performance analysis and 2) science mapping or bibliometric mapping. The former represents the impact factor and productivity, while the latter explores co-citation, coupling and keyword co-occurrence networks.

Three methods can be distinguished in bibliometric analysis: direct citations, co-citation networks and bibliographic matching (Kleminski et al., 2020) (Figure 3). Firstly, direct citations serve to identify specific information but are not usually used due to the need for long time windows (Boyack & Klavans, 2010, p. 2390). Secondly, co-citation is consistently generated by citing authors and, therefore, as citation patterns change over time, the associated topics and terms will also change. Thus, co-citation is an important element of analysis because it provides an accurate picture of the conceptual or methodological structure in one or more key disciplines, and of the interactions that may be present between approaches or between disciplines themselves (Kleminski et al., 2020; White & Griffith, 1981).

Figure 3. Types of citations



Source: adapted from Nakagawa et al. (2019)

Thirdly, bibliographic coupling measures the overlap of citations of the articles themselves (Aria et al., 2020). This enables tracking of relationships between documents, connections between different subject fields, generation of clusters between authors, between words or abstracts from co-citation structures. Bibliographic coupling is very close to collaboration and word association analysis. For this reason, by coupling between two or more documents it is understood that they have references in common. Consequently, the intensity of such coupling is determined by the number of references they have in common among that set of documents (Kleminski et al., 2020). Thus, while direct citation and bibliographic coupling are static, co-citation is dynamic and changes over time (Nakagawa et al., 2019).

2.3 Methodological review of research trends

The most common methodological approaches for analyzing the diffusion and adoption of innovations have been based on econometric models (Gruber, 2020; Ruttan, 1996). However, during the last few years, a debate has emerged in the scientific literature on the need to broaden the methodological perspective, incorporating mixed methods. These are characterized using behavioral models, social network analysis, and the study of spatial processes or methods based on focus groups, among others, responding to complementary methods to the classic econometric models. Different approaches or approaches have been developed to address the same central issue (Daouda & Bryant, 2016; Kaufmann et al., 2011; Wossen et al., 2015).

In this research, we have carried out an approach to these different methodological approaches to the investigation of the processes of adoption and diffusion of innovations in agriculture. For this purpose, based on the bibliographic coupling network, we have selected the most representative articles in each of the clusters, including in each subsection a summary table with the key elements of the main methodological research trends (section 4).

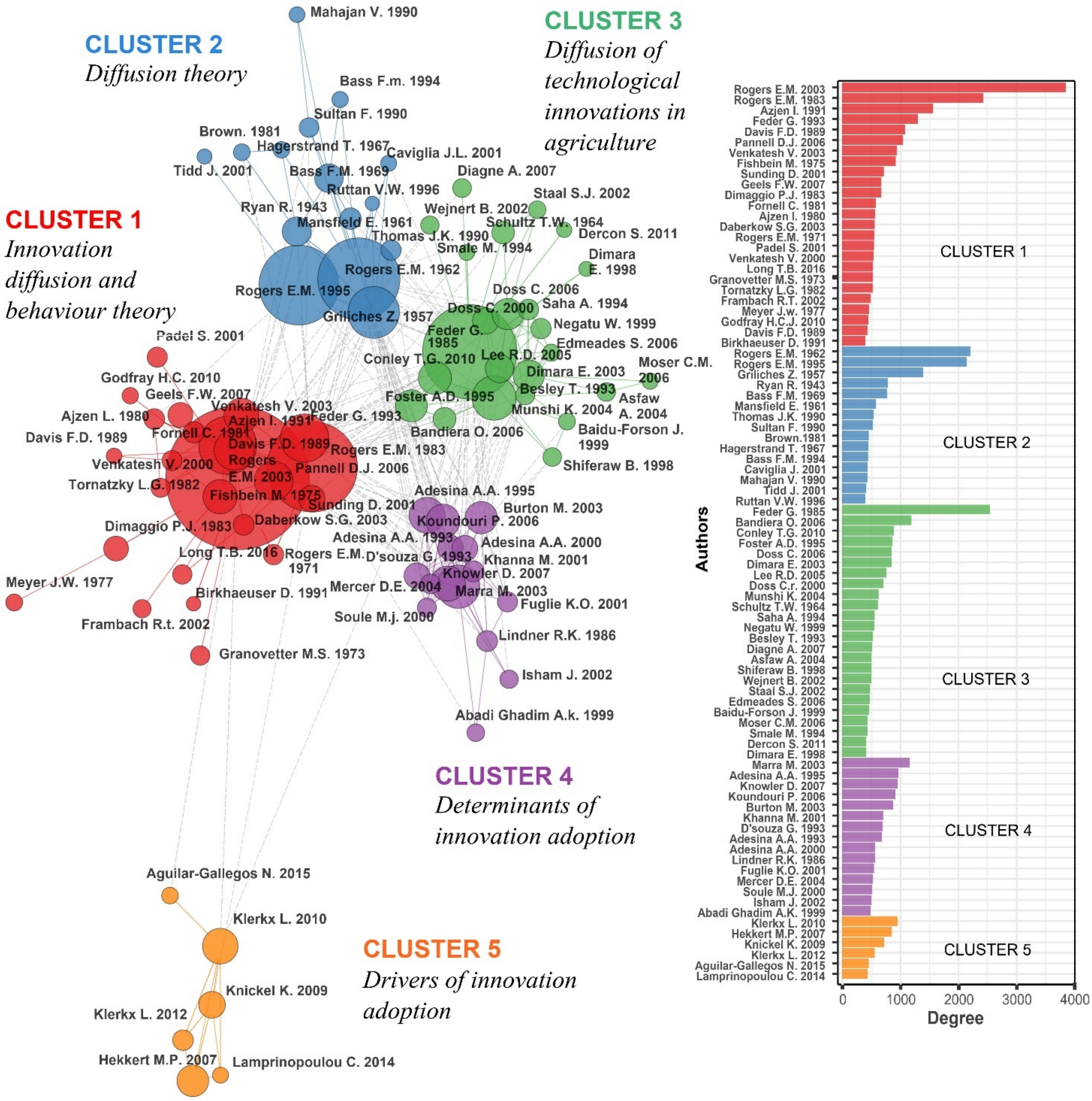
3 Co-citation network and resulting clusters: theoretical approaches

In this section, based on the co-citation network, the theoretical and conceptual foundations of the diffusion and adoption of innovations in agriculture are defined and analyzed (Adesina & Baidu-Forson, 1995; Bandiera & Rasul, 2006; Feder et al., 1985; Marra et al., 2003).

To begin with, the resulting co-citation network highlights the presence of 5 clusters clearly differentiated from each other (Figure 4). In this network we have retained only the 85 nodes that, according to their degree of centrality (degree of entry of each of the documents in question), are the most relevant. As can be seen, Rogers' research occupies especially central positions, being present in three of the five clusters of the network. These are, in fact, successive editions and updates of his classic work "Diffusion of Innovation" (Rogers, 1962, 1983, 1995, 2003). Having this reference work in common does not prevent the five clusters from being well differentiated, as highlighted by the label we have assigned to each of them. They constitute, therefore, theoretical, and conceptual pillars in research on the diffusion and adoption of innovations: cluster 1 "Acceptance Behavior Theory"; cluster 2 "Diffusion Theory and econometrics model's diffusion"; cluster 3 "Technology diffusion in agriculture", cluster 4 "Determinants of innovation adoption" y cluster 5 "Agricultural innovation systems".

Taking the above into account, in second place, a synthesis of these main theoretical pillars on the adoption and diffusion of innovations is made. As can be seen, the theoretical currents on the adoption and diffusion of innovations embrace fields of study as varied as those related to behavioral theories, institutional theory and theories of social capital (Table 4 and subsequent sections).

Figure 4. Co-citation network and resulting clusters about the adoption and diffusion of innovations in agriculture. Theoretical cornerstones



Source: authors' own elaboration

Table 4. Synthesis of the main theoretical pillars on the adoption and diffusion of innovations

Theory	Authors	Theory conceptualization
Theory of Diffusion of Innovations	Rogers (2003)	The theory of diffusion of innovations studies the process of adoption of innovations through 4 elements: 1) the innovation or idea and how it is communicated through 2) certain information channels over time 4) time within a 5) social system.
Theory of Planned Behavior	Ajzen (1991); Fishbein & Ajzen (1975)	General theory applicable to an array of behaviors, including the forces which influence the use of IT. Diffusion research applies to the behavior of accepting or rejecting an innovation. It is a widely applied expectancy-value model of attitude-behavior
Institutional theory	DiMaggio & Powell (1983)	The efforts to achieve rationality with uncertainty and constraint lead to homogeneity of structure (institutional isomorphism). Isomorphism is a "constraining process that forces one unit in a population to resemble other units that face the same set of environmental conditions".
Technology Acceptance Model	Davis et al. (1989)	The model postulates that there are two determinants of potential uptake: 1) perceived usefulness and 2) perceived ease of use. The key to this model is its emphasis on the potential perception of the potential adopter
Technology Acceptance Model 2	Venkatesh & Davis (2000)	In addition to perceived usefulness, there are subjective norms, image, job relevance, output quality and result demonstrability. These are a set of 'determinants' of perceived usefulness.
Technology Acceptance Model 3	Venkatesh & Bala (2008)	Integrated model of technology acceptance. The determinants alluded to are: 1) self-efficacy, 2) perceived external control, 3) anxiety, 4) joy, 5) perceived enjoyment and 6) objective usability.
Unified Theory of Acceptance and Use of Technology	Venkatesh et al. (2003)	To propose other constructs such as social influence, value, habit, hedonic motivation and facilitating conditions, considering age, gender and experience as moderating variables.

Table 4. Continuation

Theory	Authors	Theory conceptualization
Theory of Spatial Diffusion	Hägerstrand (1965)	The model is used to understand the processes of spatial patterns of diffusion of ideas. It creates chronological and geographical patterns generated in a process of diffusion of government subsidies for pasture improvement in Sweden.
Social Network Analysis	Granovetter (1973)	The theory argues how social interaction is influenced more than we usually appreciate by previously established weak ties with other actors with whom we have little or no contact.

Source: authors' own elaboration

3.1 Innovation diffusion and behavior theory

This cluster consists of 25 references (29% of the total network), with a very cohesive structure. Based on the works that compose it, this cluster represents well the theoretical-conceptual currents linked to the theory of diffusion, behavior and acceptance.

First of all, the works with the greatest presence are related to "Diffusion Theory", largely due to references to Rogers' "Diffusion of Innovation" (1962, 1983, 1995, 2003). The scientific literature concerning "Diffusion Theory" has a great impact on the study of adoption and diffusion of innovations and is often connected with behavioral theories to explain the innovator's attitude towards the adoption or non-adoption of an innovation (Ajzen, 1991; Fishbein & Ajzen, 1975). Therefore, to explain the attitude of potential adopters, Rogers (2003) established five main attributes in relation to innovations, such as relative advantage, complexity, compatibility, observability and trialability).

Secondly, a complementary approach, in second place in terms of importance after Rogers' contributions, is based on the "Theory of Reasoned Action" (TRA) (Fishbein & Ajzen, 1975) which, in turn, derived from Ajzen's "Theory of Planned Behavior" (TPB) (1991). According to this perspective, the more or less receptive attitude to innovations is related to other variables, such as convictions, social pressure, intentions and behavior, in order to predict human behavior. The difference between TRA and TPB is that the latter incorporates the locus of control as a determinant factor in behavioral intentions, considering that attitudes alone are not sufficient, and that the block of beliefs, social pressures and risk perception are fundamental to take behavioral intentions into account.

Thirdly, another relevant contribution based on behavioral models is the "Technology Acceptance Model (TAM)" introduced by Davis (1989). This model takes as its starting point the TRA model of Fishbein and Ajzen (1975). The TAM suggests a relationship between two variables, perceived ease of use and perceived usefulness of use. Both this and subsequent updates, such as TAM2, TAM3 and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh & Bala, 2008; Venkatesh & Davis, 2000; Venkatesh et al., 2003) highlight the robustness of this model as a key to understanding predictors of human behavior towards technology acceptance or rejection (Marangunić & Granić, 2015), and hence its prominent weight in the scientific literature on diffusion and adoption of innovations.

Fourth, the "Institutional Theory" (DiMaggio & Powell, 1983; Meyer & Rowan, 1977) is an approach that helps to explain the important influence the institutional environment can have on the development of organizational structures. In this context, the acceptance of innovative structures helps to legitimize the adoption of innovations, while their non-adoption may be considered irrational or negligent. Thus, there would be a pressure, often of a normative nature, towards homogeneity of organizational structures. This implies that there would be a tendency for organizations to be similar to each other, but not necessarily efficient (DiMaggio & Powell, 1983, p. 149).

3.2 Diffusion theory

The second group includes a total of 15 references (18% of the total network). The concept that articulates it is "Diffusion Theory", including here references on meta-analyses of the application of diffusion models, literature reviews of diffusion models and management and organization (Mahajan et al., 1990; Sultan et al., 1990; Tidd, 2001). As in the first group, the reference to Rogers' (1962) and (1995) "Diffusion of innovation" is very present. Around Rogers, pioneering studies on the adoption of hybrid maize as a type of innovation, which was adopted through the social "snowball" mechanism (Ryan & Gross, 1943), stand out. These processes responded to logistic S-curves, with profitability being a function of market density (Griliches, 1957).

Linear models for predicting diffusion resulting from word-of-mouth account for a large part of the references in this second cluster. Mansfield (1961) was one of the main authors of this approach. For his part, Bass (1969), through mathematical modeling, brought to light evidence of the "S" diffusion pattern in his work "A new product growth for model consumer durables", known as the "Bass model". This is based on the idea that "the probability of adoption by those who have not yet adopted is a linear function of those who have previously adopted".

Another important approach in the field of diffusion theory is its spatial dimension. Hägerstrand considers spatial diffusion as a fundamental phenomenon that spreads gradually over time (Hägerstrand, 1965; Hägerstrand, 1967). Two elements would be key to explain the processes of diffusion of innovations, space and hierarchy. Thus, contacts occur at a specific point in space, so that greater or lesser proximity can contribute to a greater or lesser extent to access to information, given that diffusion would occur through interpersonal communication.

The spatial modeling of the diffusion of innovations is clearly connected with the contributions of Rogers (2003), especially regarding the adoption phases: knowledge, persuasion, decision, implementation, and confirmation.

3.3 Diffusion of technological innovations in agriculture

The third cluster includes a total of 24 references (28% of the total network). Unlike the previous clusters, the third cluster includes highly cited works in research on the adoption and diffusion of innovations in agriculture. These are studies on, respectively, developing countries (Conley & Udry, 2010; Foster & Rosenzweig, 1995; Lee, 2005) and the introduction of sustainable practices in agriculture (Dimara & Skuras, 2003; Lee, 2005).

Some studies stress the need for comparable evaluations at the micro scale (Doss, 2006), others studies that have highlighted the strong impact of political decisions on the adoption of technological innovations in agriculture, for example through advisory mechanisms, credit instruments, or different regulations, among others. Feder et al. (1985) which examines the participation of the public sector as a key factor in the process of diffusion of knowledge and information on technological innovations, agricultural input markets, credit, and investment in agricultural infrastructure.

The relevance of these support systems is also evidenced in another research, more focused on the social network approach. Hence, Bandiera & Rasul (2006) explore the complexity of farmers' decision making when adopting an innovation, the effects of the network and the asymmetry between peers due to the fact that an individual may respond heterogeneously within the same network.

3.4 Determinants of innovation adoption

The fourth cluster includes a total of 15 references (18% of the total network). It is articulated around the concept of "Determinants of adoption". Whereas traditionally the determinants of adoption of innovations have been linked to economic attributes (Mansfield, 1961), the analysis of the characteristics of potential adopters, opinion leaders, communication channels and perception, have been traditionally studied by sociology, receiving less attention from economics (Adesina & Baidu-Forson, 1995; Adesina & Zinnah, 1993; Marra et al., 2003; Rogers, 2003; Ruttan, 1996).

One of the most relevant references on the determinants of the adoption of innovations is (Marra et al., 2003). This work focuses on agricultural technologies and proposes a conceptual framework that includes an analysis of the main impacts of the adoption of innovations, as well as the elements of risk derived from adoption. It also points out the importance of distinguishing between the different aspects involved in risk-taking by adopters, as well as the role of uncertainty and learning in the adoption process.

Some studies conclude that human capital (characteristics of potential adopters, such as age and, above all, education) have a weight, even more important than institutional capital, both in the decision to adopt innovations and, in general, when facing the uncertainty involved in such decisions (Isham, 2002; Koundouri et al., 2006; Souza et al., 1993). Thus, in the adoption of sustainable practices in agriculture, along with consumer demand for organic products and potential cost savings, the farmer's personal convictions stand out as a fundamental element of human capital (Souza et al., 1993). The adoption of these sustainable agricultural practices is related to the awareness of the adopters (awareness effect) that depends on the farmers' perception of the benefits they can bring (Abadi Ghadim & Pannell, 1999; Souza et al., 1993).

3.5 Agricultural innovation systems

The last of the co-citation clusters includes only 6 references (7% of the total network), forming a sub-network that connects with classic contributions in the scientific literature on the adoption and diffusion of innovations (Feder et al., 1985; Rogers, 2003). The articulating elements of this cluster, clearly differentiated from the rest, are the "agricultural innovation systems and strategies". The concept of innovation systems refers to a comprehensive approach that focuses on the analysis of the different social subsystems that contribute to the emergence of innovations, including actors and institutions. The agricultural innovation systems approach can be ranked among the most recent among systemic approaches (Klerkx et al., 2010; Klerkx et al., 2012; Lamprinopoulou et al., 2014). As (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007) points out, "If we knew what kind of activities foster or hamper innovation—thus, how innovation systems 'function'—we would be able to intentionally shape innovation processes" (p. 414).

Along this approach, reference research has been developed focusing, for instance, on the concept of multifunctionality of agriculture and rural areas, including the role of different types of gaps, social demands and the capacities of innovation and advisory agencies to induce adjustments in farms (Knickel et al., 2009). These works lead to the conclusion that for innovation to work, the support of innovation networks, such as institutions, administrations, and agricultural extension services, is necessary. This support is necessary to induce changes considering the needs of farmers, to overcome barriers to the adoption of innovations, as well as to prevent unintended consequences in the adoption process (Klerkx et al., 2010; Knickel et al., 2009).

Linked to agricultural innovation systems and not reflected in the bibliometric analysis, we have on the one hand, the contributions made by Spielman on innovation systems (Spielman, 2005; Spielman et al., 2011). Moreover, we would like to highlight the importance of the Agricultural Knowledge and Innovation Systems (AKIS) approach, for the identification, analysis, and evaluation of the various actors in the agricultural sector, as well as their communication and interaction for innovation processes (Knierim et al., 2015). This approach is widely used to investigate characteristics related to governance structures, capacity, management, social networks, advisory methods, as well as innovation support arrangements such as research, education, and innovation funding (Gava et al., 2017; Klerkx, et al., 2017; Prager et al., 2017).

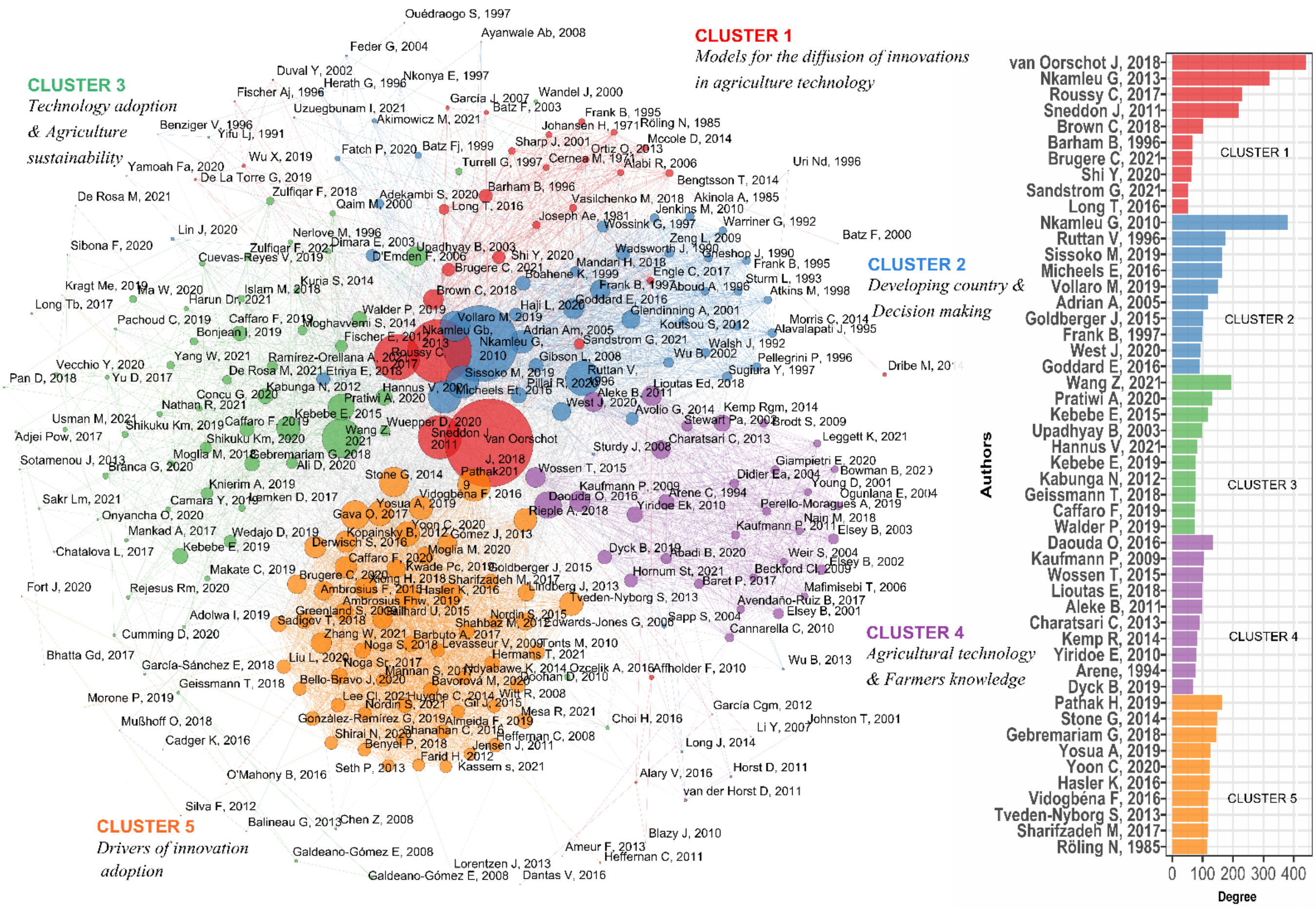
4 Coupling bibliography: methodological approaches to the analysis of diffusion and adoption of innovation in agriculture

This section reviews research trends on the adoption and diffusion of innovations in agriculture through literature coupling analysis. It should be recalled that, unlike co-citation analysis, which consists of analyzing the frequency of connection between cited authors to identify theoretical-conceptual research streams, bibliometric analysis reveals current research trends. In bibliometric analysis, current research trends are revealed through the degree of affinity of the citing authors.

Figure 5 presents, firstly, a bibliographic network with 258 publications (between 1971 and 2021), in which a total of five clusters have been defined, according to their thematic affinity. In addition, in this same Figure 5, the first 10 references with the highest degree of connection in each of the clusters have been represented in a bar graph. This is a relatively homogeneous bibliographic network where the clusters share many connections with each other, as expected. This indicates that the methodological approaches to the adoption and diffusion of innovations in agriculture are complementary to each other, with different theoretical and conceptual frameworks, different methodologies, and equally diverse practical applications. Besides, the proximity between the nodes shows the greater or lesser degree of affinity or dispersion between them (Hansen et al., 2019).

The label or characterization of each cluster is obtained from the review of the articles included in each cluster, as well as the frequencies of the keywords. Thus, the clusters can be characterized as follows according to the thematic or methodological approach: cluster 1 "Technological adoption and agricultural technology"; cluster 2 "Developing countries & decision making"; cluster 3 "Technology adoption & agriculture sustainability"; cluster 4 "Agricultural technology & farmer's knowledge"; cluster 5 "Agricultural worker & Alternative agriculture". However, different approaches and themes appear in two or more of the clusters at the same time. This is not an anomaly, but rather emphasizes that different groups of researchers use very similar methodological approaches and apply them to their different contexts and research.

Figure 5. Bibliographic coupling network and resulting clusters on the adoption and diffusion of innovations in agriculture



Source: authors' own elaboration

Table 5 shows the total number of publications, the total number of citations, the average number of citations and publications per year and, finally, the three most cited publications in each cluster. This table provides support for analyzing the most frequent methodological approaches. In each of the subsections of this same section, as mentioned above, a table is added with the methodologies frequently used for research on the diffusion and adoption of innovations in the agricultural sector.

Table 5. Summary table bibliographic coupling

Cluster	Cluster theme or approach	N° of papers	Total citations	Average cites by year (From first publication)	Average degree	Degree (Standard Deviation)	The most cited article every cluster
1	Models for diffusion of innovations in agriculture technology	34 (13%)	663 (16%)	13.26	56.11	94	(Long et al., 2016): 142
2	Developing countries & decision making	56 (22%)	1,285 (30%)	22.9	56.93	60.5	(Adrian et al., 2005): 144
3	Technology adoption & agriculture sustainability Developing countries	70 (27%)	1,021 (24%)	14.6	37.37	33.30	(Fischer & Qaim, 2012): 279
4	Agricultural technology & farmer's knowledge	36 (14%)	551 (13%)	15.5	53.81	29.5	(Wossen et al., 2015): 78
5	Drivers of innovation adoption	62 (24%)	739 (17%)	11.9	80.76	32.5	(Edwards-Jones, 2006): 211
Total		258 (100%)	4,259 (100%)	84			

Source: authors' own elaboration

The five clusters are relatively well delimited, although not free of connections between them. They can be characterized according to their size (number of publications) and, above all, aspects related to degree (which expresses the number of connections in the bibliographic internal coupling network). Thus, clusters 1 and 4 are the smallest (with 14% each of the bibliographic network), while the remaining clusters are significantly larger (between 22% and 27%). If we consider the maximum degree, clusters 1 and 2 each have one publication with a particularly central role (440 and 380 respectively). In the remaining clusters, this preponderant role of a single publication in the coupling network is more diluted (194 for cluster 3, 135 for cluster 4 and 164 for cluster 5).

The average degree of each cluster is an interesting indicator in that it highlights the average number of connections (citations) between the publications that make up that cluster. It is therefore an indicator of the density of relationships. Cluster number 5 is, with a clear difference from the rest, the one that presents the highest average degree, that is, the highest density of connections between all the publications (and, therefore, between the authors, at least at the level of mutual citation of the respective papers). This is also noteworthy in view of the fact that this high density of connections occurs despite the comparatively high number of publications.

Clusters 1, 2 and 4 present average levels, while cluster 3 presents the lowest density of relationships in comparative terms. This means that many of the publications included here do not have particularly strong links between them, and can even be said to be more isolated.

Complementing the average degree, the SD shows the internal dispersion within each cluster. Thus, three of them (3, 4 and 5) have a comparatively low SD, i.e., average distances between publications (authors) are lower and more homogeneously distributed. This is why in these three clusters the differences between the highest and lowest ranked node or publication are much lower than the differences in the remaining two clusters. Indeed, clusters 1 and 2 present a comparatively high SD, which derives from the presence of a very small number of publications with very central positions. Thus, in cluster number 2, only one publication occupies a very central position, whereas in cluster number 1 this centrality is more distributed among four publications. Thus, here the difference between the publication with the highest and the lowest degree is much greater, as can be seen in Figure 5).

In any case, the above data do not call into question the internal coherence of any of the clusters, so that all of them highlight well-defined (but obviously not totally independent) thematic associations, as will be seen below. Nor can it be said that one is more effective or better than another. They are simply sets of publications in different contexts, with particular emphasis on that which characterizes clusters 1 and 2, where there is a clear dominance around a very small number of very central publications, and clusters 4 and 5 and, to a lesser extent, 3, where the dominant position of a small number of publications is much more diluted.

4.1 Models for the diffusion of innovations in agriculture technology

Given the detected research trends we have named this cluster "Models for the diffusion of innovations in agricultural technology" and the authors with the highest number of citations are (Batz et al., 2003; Long et al., 2016; van Oorschot et al., 2018) with 142, 69 and 57 respectively. The topic "Models for the diffusion of innovations in agricultural technology" is fairly well represented in the literature, especially from the last two decades, highlighting the work of Batz et al. (2003) and, at some distance from this research, largely because they are more recent, are among the most cited, the works of Long et al. (2016) and the bibliometric review of van Oorschot et al. (2018). Research based on diffusion models, however, is highly interconnected with cluster two, on "Developing countries & Decision making" through several references with central positions within the network (Nkamleu, 2010; Sneddon et al., 2011; van Oorschot et al., 2018).

The methods of analysis used by the papers constituting this cluster are varied, including qualitative methods, through interviews and discourse analysis (Long et al., 2016), and quantitative, based on diffusion models (Sneddon et al., 2011). The latter are mainly based on diffusion theory (Bass, 1969; Rogers, 2003), but also on econometric models (Alary et al., 2016). In addition, review papers, which analyze the innovation adoption literature broadly and comprehensively, stand out (Roussy et al., 2017; van Oorschot et al., 2018).

Theoretical streams complement each other and combine several approaches as a means of research. For example, the "Theory of Planned Behavior" in combination with the "Diffusion Theory" (Rogers, 2003) aims to gain insights into the attitude and determinants for the adoption of innovations (Brugere et al., 2020).

Scientific literature has shown that there are agronomic, economic and psychosocial determinants that affect decision-making on the adoption of innovations (Long et al., 2016; Roussy et al., 2017; van Oorschot et al., 2018). One example is the development of agroecology, a complex innovation that aims to reconcile agricultural productivity with environmental protection, in which classical agronomic techniques are combined with innovative production techniques. Within this innovation, in addition to these tangible factors, there are others, less tangible, such as individual perceptions, which can be of great relevance (Roussy et al., 2017). The barriers affecting tangible factors linked to the adoption of innovations are being widely studied. This has been highlighted by Long et al. (2016) in their study on barriers to the adoption of innovations both on the supply side (technology suppliers and members of the agricultural supply chain) and on the final demand side (users).

As for the less tangible factors, the lack or insufficiency of information can explain the existence of lags and, therefore, the partial adoption of innovations (Fischer et al., 1996). Lack of training is closely related to the availability of adequate information, especially when it directly influences the ability to adopt and manage complex technologies, as well as the speed of their adoption (Batz et al., 2003; Batz et al., 1999). Other studies highlight the importance of both the social context in which adopters are situated and the interaction between farmers and agents (Ortiz et al., 2013; Shi et al., 2020; Sneddon et al., 2011).

Spatial diffusion models are very prominent in the analysis of innovation diffusion (Brown et al., 2018; Johansen, 1971; Joseph & Keddie, 1981). In this regard, relevant research builds on Hägerstrand's (1965) contributions on the influence of major community centers on communication patterns among farmers (Johansen, 1971), changes in adoption rate (Joseph & Keddie, 1981), and time lags that remain characteristic of the adoption of new management practices (Brown et al., 2018).

Table 6. Main research methods on the adoption and diffusion of innovations in the cluster 1

Publications	Main field research	Research method/ model	Method/model operation	Method/ model references
Sneddon et al. (2011)	Drivers of adoption	Bass diffusion model	It is applied to investigate the process of adoption of new products in a population. Adopters can be innovators or imitators. The speed and timing of adoption depends on their degree of innovation and the degree of imitation among adopters.	Bass (1969); Rogers (2003)
Fischer et al. (1996)	Time of adoption	Bayesian model	The model is used for accounting for empirically observed lags within the time lags between when farmers learn about an innovation and when they adopt it.	Feder & O'Mara (1982)
Batz et al. (1999, 2003)	Innovation diffusion	Speed innovation adoption model	The model explains the speed of adoption in relation to the characteristics of the new and traditional technology.	Adesina & Zinnah (1993)
Joseph & Keddie (1981) Brown et al. (2018) Johansen (1971)	Innovation diffusion	Spatial diffusion model	Logistic model of spatial dependencies to find evidence of new crop adoption and subsidies with spatial diffusion.	Hägerstrand, (1965, 1967)
Blazy et al. (2010) Alary et al. (2016)	Management innovations	Bio-econometri c model	Bio-economic farm model based on the optimization of a utility function under multiple constraints, capturing the interactions between livestock activities and the introduction of no-tillage mulch-based cropping systems.	Affholder et al. (2010); Brown (000)
Fu et al. (2007)	Behavior adoption	TAM model	Examines perceptions and attitudes toward m-commerce adoption from the perspective of innovation adoption.	Davis et al. (1989); Fishbein & Ajzen (1975)
Shi et al. (2020)	Technology adoption	Agents based model	Explores whether and how such an information platform affects the diffusion of energy efficiency technologies in small and medium-sized enterprises, this study builds an agent-based model to mimic the processes of diffusion of energy efficiency technologies.	Bassm (1969)

Source: authors' own elaboration

4.2 Developing countries & decision making

This second cluster includes has been labeled as "Developing countries & Decision making" due to the most relevant research (Akimowicz et al., 2021; Ruttan, 1996; Wu & Zhang, 2013), among which the only book included in this cluster (Nkamleu, 2010) stands out. This work addresses the problem of low agricultural yields and the food crisis in sub-Saharan Africa, and explores the missing links in knowledge transfer that, to a large extent, explain the failure of technology diffusion. In this sense, they highlight, as do many other authors, the key and critical importance of knowledge transfer through intermediate actors, without which adequate adoption of agricultural innovations is often not achieved (Akimowicz et al., 2021; D'Emden et al., 2006; Fatch et al., 2020; Feder et al., 2004; Vollaro et al., 2019).

Scholars have addressed this issue with different methodological approaches, through econometric, behavioral, perception and learning models, and social capital analysis, both in developing and Western countries (Adrian et al., 2005; Alavalapati et al., 1995; Micheels & Nolan, 2016; Pillai & Sivathanu, 2020).

Using econometric models, the influence of public institutions on the market, through different mechanisms, is emphasized (Goddard et al., 2016; Vollaro et al., 2019). Using these same approaches, specific cases have been analyzed, such as the one highlighting the importance of farmer training to adopt technology packages ("technology ladder") in Tanzania (Nkonya et al., 1997). Learning, and consequently the availability of access to knowledge and information for the adoption of innovations, is one of the factors to which, also from these approaches, more attention has been paid for the analysis of the adoption and diffusion of innovations (D'Emden et al., 2006; Fatch et al., 2020; Yifu, 1991).

Further econometric analyses also incorporate the perception of net benefit, farm size and educational level as elements that, according to the results obtained, positively influence the adoption of precision farming. Thus, Wossink et al. (1997) emphasized that decisions to adopt environmentally friendly techniques are not based exclusively on environmental and economic benefits, but also on the perception and availability of an adequately educated labor force. Similarly, Pillai and Sivathanu (2020), based on behavioral reasoning theory, focused their research on the adoption of the Internet by farmers in India, and concluded that the reasons for the adoption of innovations included the influence of the social environment, the positive perception that they were convenient and useful innovations.

The particularly important role of information and training in developing countries was emphasized by Feder et al. (2004), demonstrating the particularly positive relationship between training and the adoption of sustainable integrated pest management practices. Nevertheless, the environment in which innovations are successfully adopted, also in developing countries, is influenced by government involvement, agricultural extension agents and farmer leadership. It is thus a kind of innovation ecosystem in which all elements are necessary farmers adopt innovative solutions according to their situation, needs and perspectives (Akimowicz et al., 2021; Wu & Zhang, 2013).

Positive bias, in part derived from the role of local leaders, is relevant in all contexts. Emphasis is placed on the importance of the role of social capital associated with increased technologies to improve business practices and outcomes Micheels & Nolan (2016), access to information and use of technique, as shown by the work of D'Emden et al. (2006) on the adoption of soil conservation farming practices by grain producers, through a behavioral model.

In terms of social interactions, young farmers are an important part of the diffusion of agricultural innovations, yet they are often trapped in traditional structures. Koutsou & Partalidou (2012) analyze the minorities of innovators who move from being passive subjects, to stimulating innovation systems, and encourage the support of these with the aim of provoking a change action that motivates non-adopters.

Within this same cluster 2 we found two studies with a gender focus in developing countries (Aboud et al., 1996; Mandari & Chong, 2018). They enhance the role of agrarian women and suggest that women have a slightly higher level of adoption in various conservation practices.

Table 7. Main research methods on the adoption and diffusion of innovations in the cluster 2

Publications	Main field research	Research method/ model	Method/model operation	Method/ model references
Adrian et al. (2005)	Precision agriculture	Structural equation modeling	This document reports research on the perception and attitudinal characteristics of farmers planning to adopt these technologies. A survey tool is used to measure perception and attitudinal constructs.	See Adrian et al. (2005)
Alavalapati et al. (1995)	Agroforestry practices adoption	Logit model	The study analyzes the factors that influence the adoption of agroforestry practices.	Rogers (2003); Souza et al. (1993)
Boahene, Snijders, & Folmer (1999)	Agricultural innovations	Logistic regression model	To explain the adoption of agricultural innovations in developing economies.	Hosmer Jr, Lemeshow, & Sturdivant (2013)
Feder et al. (2004)	Knowledge diffusion	Knowledge acquisition model	This document uses panel data from Indonesia to assess the degree of dissemination of integrated pest management knowledge from trained farmers to other farmers.	Griliches (1957)
Haji, Valizadeh, Rezaei-Moghaddam, & Hayati (2020)	Behavioral intention	TAM model	Introduction of existing models of acceptance behavior, comparison of these theories with a critical point of view, presentation of a theoretical framework based on TAM and testing of possible relationships between variables	Davis et al. (1989)
Micheels & Nolan (2016)	Social capital Knowledge networks	Social Capital	The study examines how structural factors, such as farm size and life cycle, and individual factors, such as social capital and absorptive capacity, affect the adoption decision among cattle farms.	Molina-Morales & Martínez-Fernández (2010)
Yifu (1991)	New technology adoption	Probit model	Used to estimate the probability that an observation with particular characteristics would fall into a specific category.	Jamison & Lau (1982)

Source: authors' own elaboration

4.3 Technology adoption and agriculture sustainability in developing countries: the predominance of quantitative approaches

This cluster has been labeled "Technology adoption & Agriculture sustainability". It includes research addressing aspects such as supportive public policies and the crucial role of extension agents, all within the framework of "sustainable agriculture, capacity building and training, or the role of gender in relation to the adoption of innovations (Bhatta et al., 2017; Branca & Perelli, 2020; Chatalova et al., 2017; Concu et al., 2020; Harun et al., 2021; Knierim et al., 2019; Mankad et al., 2017; Moglia et al., 2020; Ozcelik, 2016; Wedajo et al., 2019). Dissemination of knowledge to users is equally important (Harun et al., 2021; Rejesus & Jones, 2020; Usman et al., 2021).

Indeed, technology adoption and sustainable agriculture are two concepts that are commonly linked in the scientific literature about the diffusion and adoption of agricultural innovations and have often been studied in developing countries (Onyancha & Onyango, 2020; Yamoah et al., 2020). Nevertheless, the concept of "sustainable agriculture" is ambiguous in the sense that the criteria for sustainability differ according to the type of farming system. Thus, any attempt to distinguish some technologies and systems as "sustainable" risks implying that others are not (Schaller 1993; Lee 2005). Moreover, in developing countries, true sustainability has to include aspects such as food security or income in rapidly growing populations (Lee, 2005). In relation to these countries, FAO (1989) has already defined five main attributes: resource conservation, non-degradation of the environment, technically feasible, and economically and socially acceptable.

Among the most impactful research in this network is that of (Wang et al., 2021), which focuses on the need to adopt innovations to mitigate the impact of practices in Chinese agricultural production, using a "technology-organization-environment" methodological framework. Their results suggest that relative advantages, as well as support from agricultural extension services, have a positive effect on the adoption decision.

Several studies have analyzed the role of farm size in the adoption of sustainable practices. Nonetheless, no conclusive results have been reached (Cuevas-Reyes, 2019; Makate et al., 2019; Walder et al., 2019; Wang et al., 2021). The environment may condition the importance of this variable, and thus, while in the case of China (Wang et al., 2021), it is concluded that farm size does not influence the adoption of sustainable practices, research in Italy on "smart agriculture", highlights that these types of innovations tend to be adopted comparatively more by larger farms (Caffaro & Cavallo, 2019, 2020).

Some research in developing countries emphasizes the barriers to the adoption of technological innovations, such as the absence of key actors, limited capacities (and training), farmers' insecurity about property rights (Kebebe et al., 2015), or the limited interaction between agents involved in different stages of the value chain, especially input and output markets (Kebebe, 2019).

Regarding the acquisition and dissemination of information and knowledge on agricultural practices and innovations, it is not only the presence of certain agents (for instance those linked to training) that is important. The central position and close links in the social network are equally important (Cadger et al., 2016; Pachoud et al., 2019; Zulfiqar et al., 2021). Hence, low interaction, reduced collective action among key actors, or very weakened leaderships would have direct negative effects on the adoption of innovations. For this reason, institutional arrangements may be necessary instruments to favor cooperation between the different actors in the system and achieve greater success in the adoption of agricultural innovations (Pachoud et al., 2019).

Finally, there is an interesting study on the role of women in the adoption of innovations. It refers to traditional lifestyles in Laos, and concludes that it is precisely women who, compared to men, are acquiring a greater role in non-agricultural work, in everything related to insertion in the modern economy, which is an important organizational innovation within families (Moglia et al., 2020).

Table 8. Main research methods on the adoption and diffusion of innovations in the cluster 3

Publications	Main field research	Research method/ model	Method/model operation	Method/model references
Knierim et al. (2019)	Smart farming	Multi-actors' approach	Multi-actors' approach (mixed method). A comprehensive situational picture was compiled to evaluate smart agricultural technologies.	Geels (2002; Klerkx et al. (2010)
Hannus & Sauer (2021) Harun et al. (2021)	Decision making	Structural equation model (SEM)	To evaluate the individual factors that influence the decision-making process within the technology acceptance model (TAM).	Davis et al. (1989); Kline (2015)
Dimara & Skuras (2003)	Partial observability	Partial observability model	A proposal for models that allow a flexible specification of adoption from one to two stages	Saha, Love, & Schwart (1994)
Moghavvemi & salleh (2014)	Individual's technology acceptance	Technological acceptance model	To review and validate this model in the context of technological acceptance, while investigating the adoption of information technology innovation.	Ajzen (1991); Krueger & Carsrud (1993)
Chatalova et al. (2017)	Institutional dichotomy	Institutional analysis	It is based on the institutional approach that shows the possibility of technological innovations being encapsulated by dysfunctional institutions.	Feder & Umali (1993); Ramstad (1990)
Adolwa, Schwarze, Waswa & Buerkert (2019)	Technology adoption	Stratified sample	Randomized selection model to evaluate how different factors at plot, farm and institutional levels are evaluated	Long & Freese (2006)

Source: authors' own elaboration

4.4 Agricultural technology & farmers knowledge

The approaches or themes around which the research of this cluster is articulated can be defined as "Agricultural technology & farmers knowledge". These researches present many connections with those contained in cluster 1, although they also present points of contact with those of clusters 2 and 5, meaning that we will find shared references (coupled) with these clusters. The main difference compared to the previous cluster is that while in that cluster the use of quantitative models predominated, here they have much less presence, and qualitative approaches, such as interviews and focus groups, become dominant.

Specific papers on the periphery of the cluster focus on selected areas of study, supported by the theories of diffusion of innovations. Two examples are the one referring to bacteriological cultivation (Bowman et al. , 2020) and the study of factors influencing adoption of innovations for integrated pest management (Elsey & Sirichoti, 2003) using approaches based on theories of education (Chanyapate, 2018; Rogers, 1993). Further, more significant studies also take solid references, such as the theoretical foundations of behavioral theories (Ajzen, 1991), diffusion of innovations and social capital theory (Granovetter, 1973; Rogers, 2003). In its application to agricultural research, some investigations consider that the adoption of innovations on farms responds mainly to economic reasons, such as subsidies. These would be key to adopt organic farming, as highlighted, among others, by studies on the behavior of farmers in Latvia and Lithuania (Kaufmann et al., 2009; Kaufmann et al., 2011), or those referring to economic incentives for the adoption of "green" innovations (Lioutas & Charatsari, 2018). In the latter case, a prediction model is used based on possible motives for adoption, such as "adaptation to the social process of innovation diffusion, environmental concern, convenience, economic incentives and internal need to pursue change".

In this sense, other research, which starts from the theoretical pillars of social capital (Bandiera & Rasul, 2006; Rogers, 1995; Young, 2009), considers that it plays an essential role in the adoption of sustainable practices for the improvement of agricultural land management, in environments as apparently diverse as Ethiopia (Wossen et al., 2015), and Scotland (Yiridoe, Atari, Gordon, & Smale, 2010).

In a different setting, in relation to information channels and, specifically, the use of the Internet in agriculture, research conducted in Greece indicates that in the early stages of agricultural information, access to the Internet can be effective. However, as progress is made and problems or very specific issues arise, the usefulness of the internet decreases and personal contacts with experts become necessary (Charatsari & Lioutas, 2013).

Overall, much of the research in this cluster refers to social capital and social ties (Brown & Reingen, 1987; Granovetter, 1973; Hansen, 1999), with the understanding that decision making involving the adoption of innovations is a social process. Namely, the decision-maker must have, more or less explicitly, the approval of the members of the social system to which he or she belongs, within the context, behavioral patterns and pre-established social norms. Thus, for example, a study on social groups in Quebec shows how social relations at the local level were the basis for the emergence of both material and immaterial innovations, both to introduce innovations aimed at combating the effects of climate change and other types of innovations (Daouda & Bryant, 2016).

Table 9. Main research methods on the adoption and diffusion of innovations in the cluster 4

Publications	Main field research	Research method/ model	Method/model operation	Method/model references
Wossen et al. (2015)	Social influence	Social capital	To analyze the importance of social capital in the adoption of improved agricultural land management practices.	Bandiera & Rasul (2006); Mafimisebi et al. (2006); Rogers (1995)
Kaufmann et al. (2009)	Social influence	Logit Model	To understand the dominant reason for the adoption of organic farming in Lithuania.	Ajzen (1991); Rogers (1995); Valente (2005)
Daouda & Bryant (2016)	Decision making	Focus Group	To analyze leadership relationships for the adoption of innovations for climate change adaptation.	Goldberger (2008); Granovetter (1973); Rogers (1995)
Lioutas & Charatsari (2018)	Adoption decision	Survey	To examine factors influencing adoption and motives that predict the adoption behavior of green innovations.	Ajzen & Fishbein (1980); Burton et al. (2003); Rogers (1962)
Yiridoe et al. (2010)	Information	Discrete choice model	To analyze information channels and sources for the adoption of conservation practices.	Rogers (2003); Souza et al. (1993)

Source: authors' own elaboration

4.5 Drivers of innovation adoption

The general trend of research revolves around the "Drivers of innovation adoption", and this comprises organizational factors, perception and trust, social and cultural factors, interpersonal communication, learning and training, and mental models. Among the wide variety of research on adoption factors, two review papers are worth highlighting. The first is a methodological review (Edwards-Jones 2006), with a very prominent position in the network. It provides a revision of quantitative methods, which have been applied in agricultural research for many years, combining economic and behavioral models, the latter coming from psychology (Austin et al., 1998; Fishbein & Ajzen, 1975). The second review paper, although less prominent in the network, is of interest because it is a systematic analysis of precision agriculture in the context of the diffusion of innovations, based on a total of 34 articles. The authors conclude that many of the multidimensional determinants of innovation diffusion (Ajzen, 1991; Davis et al., 1989; Knickel et al., 2009), which had been developed in industrial contexts, were absent in the adoption of precision technologies in agriculture (Pathak et al., 2019).

Nonetheless, it is clear that there are several factors that influence the adoption of agricultural innovations, as we have seen up to this point. Thus, in a study conducted on a smart farm, based on Rogers' (2003) innovation diffusion model, it was shown that the adoption of innovations responded to the combination of aspects such as technological compatibility, financial costs for the organization and changes in the digital environment (Hasler et al., 2016). Similarly, two other researches related to the role of organizations in accelerating the diffusion of innovations highlight the central role of opinion leaders and institutions (Mesa & Esparcia, 2021; Yosua et al., 2019) and the importance of formal leaders in generating trust for the adoption of agri-environmental measures (Gailhard, Bavorová, & Pirscher, 2015). Part of these works, directly or indirectly, are developed under the approach "agricultural innovation systems" and "Agricultural Knowledge and Information System" (Gailhard et al., 2015; Hasler et al., 2016) by considering interaction processes beyond the farm level and the transfer of knowledge between agents (Klerkx et al., 2010).

A study based on more than 200 surveys among vegetable producers in Benin relates confidence in adopting an innovation (installation of netting) to aspects such as farm size, distance to agricultural extension services, as well as farmers' experience (Vidogbéna et al., 2016). This is the reason why communication and interpersonal learning can decrease the knowledge gap, as several researches argue, such as the one referring to rapid learning on websites (Tveden-Nyborg et al., 2013), or to the training of farmers in "field schools" in Senegal (Witt et al., 2008). Finally, some research highlights how farmers' confidence in adopting innovations may be determined more by social and cultural factors than specifically economic ones (Gil et al., 2015; Heffernan et al., 2008), as well as being subject to cyclical fashions (Stone et al., 2014).

Table 10. Main research methods on the adoption and diffusion of innovations in cluster 5

Publications	Main field research	Research method/ model	Method/model operation	Method/ model references
Pathak et al. (2019)	Precision agriculture	Systematic review	Systematic review of the literature to explore the adoption processes of precision agriculture technologies.	Ajzen (1991); Knickel et al. (2009); Rogers (2003)
Gil et al. (2015)	Embedded systems	Surveys	Evaluation of integrated systems in Mato Grosso described in terms of their main technical and non-technical characteristics.	Rogers (2003)
Yosua et al. (2019)	Opinion leaders	Model agent-base	To analyze the effectiveness of opinion leaders in accelerating the diffusion of innovations.	Besley & Case (1993)
Hasler et al. (2016)	Innovation systems	Model diffusion of innovation	The model proposes that the adoption of an innovative technology is influenced by the relative advantages, complexity and compatibility of the technology, the innovativeness and knowledge characteristics of the CEO's.	Davis et al. (1989); Klerkx et al. (2010); Rogers (1995)
Vidogbéna et al. (2016)	Sustainable systems	Likert & Model probit	An organized probit model to determine which network characteristics were the most influential.	Dimara & Skuras (2003); Feder et al. (1985)
Sharifzadeh, Damalas, Abdollahzadeh, & Ahmadi-Gorgi (2017)	Biological control strategies	Technology Acceptance Model (TAM2)	To analyze perceived self-efficacy and facilitating conditions to investigate factors affecting acceptance and use of biological control in rice.	Rogers (2003); Venkatesh & Davis (2000)
Gailhard et al. (2015)	Interpersonal communication	Social Networks Analysis	To investigate the impact of interpersonal communication on the adoption of agri-environmental measures.	Bandiera & Rasul (2006); Rogers (2003)

Source: authors' own elaboration

5 Discussion and conclusion

Throughout this paper, a systematic review of the scientific literature particularly relevant to the adoption of innovations in agriculture during the last 50 years (1971-2021) has been presented, based on an initial selection of 353 articles. This review aims to expose the main research trends and identify the theoretical cornerstones on which they are based. To this end, two tools frequently used in bibliometric analysis, co-citation networks and bibliographic coupling, have been employed. Co-citation provides an accurate picture of the conceptual or methodological structure in one discipline or research topic through the interactions (connections) between authors cited in the selected publications. On the other hand, bibliographic coupling enables tracking of relationships between documents, that is, connections between different subject fields, allowing the generation of clusters between authors (through the analysis of references that those authors have in common).

Firstly, through the co-citation network, five major approaches or theoretical-conceptual approaches to the adoption and diffusion of innovations in agriculture were identified, although there are not completely independent so they maintain some connections with each other: 1) Innovation diffusion and behavior theory; 2) Diffusion theory; 3) Diffusion of technological innovations in agriculture; 4) Determinants of innovation adoption; and 5) Agricultural innovation systems. The central author who clearly dominates the different approaches to the diffusion of innovations is Rogers (2003), despite the fact that other authors are also very prominent (Ajzen, 1991; Davis, 1989; Feder & Umali, 1993; Griliches, 1957).

Thus, in the co-citation network we find that the first cluster, ''Innovation diffusion and behavior theory", is closely linked to Diffusion Theory due to the seminal and well-known publication "Diffusion of Innovation" by Rogers (1962, 1983, 1995, 2003). However, "Diffusion Theory" has been complemented by other contributions, such as "Theory of Reasoned Action" (Fishbein & Ajzen, 1975) or Ajzen's "Theory of Planned Behavior" (1991). The combined application of the "Diffusion Theory", the "Theory of Reasoned Action" and the "Theory of Planned Behavior" has been reflected in various pieces of research, where human behavior is studied in relation to the diffusion of innovations.

The second cluster of the co-citation network is focused on "Diffusion theory", including references on meta-analyses of the application of diffusion models, literature reviews of diffusion models and management and organization (Mahajan et al., 1990; Sultan et al., 1990; Tidd, 2001) in addition to the very present writings by Rogers (1962, 1995). Diffusion models have been widely applied in different disciplines such as agriculture, through pioneering studies such as that of hybrid corn (Ryan & Gross, 1943). Diffusion models have also been applied in marketing studies, with the aim of understanding the adoption processes of certain products (Bass, 1969). In the field of geography, research on spatial diffusion has a long history of study

(Hägerstrand, 1965, 1967). Here, spatial modeling is connected with the theory of diffusion of innovations on the phases of adoption knowledge, persuasion, decision, implementation and confirmation. However, some geographers have gone further, suggesting the need to incorporate aspects such as risk, uncertainty, as well as adoption patterns into the spatial dimension (Marra et al., 2003; Ruttan, 1996).

The third cluster of the co-citation network revolves around the "Diffusion of technological innovations in agriculture". It includes research that is frequently cited in studies related to agriculture (Conley & Udry, 2010; Foster & Rosenzweig, 1995; Lee, 2005) (Conley & Udry, 2010; Foster & Rosenzweig, 1995; Lee, 2005) and the introduction of sustainable practices in agriculture (Dimara & Skuras, 2003; Lee, 2005). Some of this research has also highlighted the importance of social and behavioral learning mechanisms in decision making (Besley & Case, 1993; Conley & Udry, 2010), as well as the structure of social relationships (Granovetter, 1973)

The fourth cluster of the co-citation network is related to the "Determinants of innovation adoption" whose analysis has traditionally been linked to economic attributes. However, the analysis of the characteristics of potential adopters, opinion leaders, communication channels and perception have traditionally been studied by sociology, receiving even less attention from economics (Adesina & Baidu-Forson, 1995; Adesina & Zinnah, 1993; Marra et al., 2003; Rogers, 2003; Ruttan, 1996). In this cluster, references include Marra et al. (2003). Their research focuses on agricultural technologies, proposing a conceptual framework that includes an analysis of the main impacts of the adoption of innovations as well as the risk elements derived from adoption.

The fifth cluster of the co-creation network is linked to "Agricultural innovation systems". It differs from the rest by gathering specific elements related to agricultural innovation systems and strategies. The concept of innovation systems refers to a global approach that focuses on the analysis of the different social subsystems that contribute to the emergence of innovations, including actors and institutions. Within this approach, leading research has been developed, focusing on the concept of multifunctionality of agriculture and rural areas as well as the role of different types of gaps, social demands and the capabilities of innovation agencies (Knickel et al., 2009). These papers emphasize the need for support to induce change and overcome barriers to the adoption of innovations (Klerkx et al., 2010; Knickel et al., 2009).

Secondly, using the bibliographic coupling tool, the main current research trends were reviewed. Here we have also obtained five relevant clusters, which correspond to five large areas of research, also with many points of connection between them in terms of topics and fields, but which constitute differentiated schools. Therefore, each of the labels with which each of them is identified are not mutually exclusive. These are 1) Models for the diffusion of innovations in agriculture technology 2) Developing country & and decision making 3) Technology adoption & agriculture sustainability 4) Agricultural technology & farmers knowledge 5) Drivers of innovation adoption.

The first cluster of the coupling network is related to "Models for the diffusion of innovations in agriculture technology". In this cluster, research by Batz et al. (2003), Long et al. (2016) and the literature review by van Oorschot et al. (2018) are highlighted. Different methodological approaches are combined, with qualitative (Long et al., 2016) and quantitative methods (Sneddon et al., 2011). In terms of content, the different agronomic, economic and psychosocial determinants affecting decision-making in the face of innovation adoption are (Long et al., 2016; Roussy et al., 2017; van Oorschot et al., 2018).

In close connection with the previous one, the second cluster of the coupling network is labeled "Developing countries & Decision making". Here we find outstanding research on the problems of low agricultural yields and food crises in sub-Saharan Africa (Nkamleu, 2010). Other research focuses on the transfer of knowledge through intermediate actors, which are of key importance, since without them it would be difficult to adequately adopt agricultural innovations (Akimowicz et al., 2021; D'Emden et al., 2006; Fatch et al., 2020; Feder et al., 2004; Vollaro et al., 2019). Similarly, other authors have highlighted the importance of information and training in developing countries for the adoption of agricultural innovations (Feder et al., 2004)

The third cluster of the coupling network has been named "Technology adoption and Agriculture sustainability in developing countries: the predominance of quantitative approaches". It includes research addressing aspects such as supportive public policies and the crucial role of extension agents, all within the framework of sustainable agriculture, capacity building and training, or the role of gender in relation to the adoption of innovations (Bhatta et al., 2017; Branca & Perelli, 2020; Chatalova et al., 2017; Concu et al., 2020; Harun et al., 2021; Knierim et al., 2019; Mankad et al., 2017; Moglia et al., 2020; Ozcelik, 2016; Wedajo et al., 2019). Among the most impactful research in this network is that of (Wang et al., 2021), which focuses on the need to adopt innovations to mitigate the impact of practices in Chinese agricultural production, using a "technology-organization-environment" methodological framework. Other studies collected in this cluster have analyzed the role of farm size in the adoption of sustainable practices (Cuevas-Reyes, 2019; Makate et al., 2019; Walder et al., 2019; Wang et al., 2021), the importance of the environment as a conditioning factor (Wang et al., 2021) and the absence of key actors in studies conducted in developing countries as limiting factors, as well as the low interaction between agents (Kebebe et al., 2015).

The fourth cluster of the coupling network focuses on "Agricultural technology & farmers knowledge". In this cluster, qualitative approaches (interviews and focus groups) have a greater presence. Much of the research in this cluster refers to social capital and social ties (Brown & Reingen, 1987; Granovetter, 1973; Hansen, 1999), with the understanding that decision making involving the adoption of innovations is a social process. These investigations take solid references based on the theoretical foundations of behavioral theories (Ajzen, 1991) and the diffusion of innovations.

The fifth cluster of the coupling network, which we have defined as "Drivers of innovation adoption", includes the study of organizational factors, perception and trust, social and cultural factors, interpersonal communication, learning and training, and mental models. Methodological review papers such as Edwards-Jones (2006) review quantitative methods applied in agricultural research in combination with economic and behavioral methods (Austin et al., 1998; Fishbein & Ajzen, 1975). Other prominent research has shown that the adoption of innovations responded to aspects related to technological compatibility, financial costs for the organization and changes in the digital environment (Hasler et al., 2016).

This review has shown that the adoption and diffusion of innovations in agriculture is studied from different fields, schools, and theoretical-conceptual approaches, but that there is also a very high connection between all of them. This makes research on the adoption and diffusion of innovations in agriculture more complex, but also more complete and increasingly comprehensive. This is clear from the obvious overlaps between the different clusters, but also from the involvement of different disciplines. All this confirms that this research is increasingly adding value by incorporating, often in combination, a greater number of perspectives and variables. The trend towards the predominance of multivariate analysis methodologies, based mainly on quantitative models, is therefore understandable.

Along the same lines, the publications that illustrate the processes of adoption and diffusion of innovations in agriculture, directly and indirectly, also reveal the barriers and limitations in such processes. These limitations have traditionally been analyzed almost exclusively from an economic point of view. However, in recent years, studies on human behavior and perception have been fundamental in analyzing the limitations and, thus, advancing in predictive models on the behavior of the different actors (especially farmers) in the adoption of innovations.

As previously mentioned, the diffusion and adoption of innovations are different processes, although they are certainly complementary. Research focused on diffusion processes tends to focus on the critical mass of adopters or non-adopters, the speed and rapidity of diffusion, spatial characteristics, and other probability models. Adoption processes, on the other hand, are often studied together with diffusion processes, but adoption often focuses on factors related to behavior, perception, risk aversion or relative advantage.

For both diffusion and adoption processes, researchers have developed and fine-tuned multivariate methodological approaches. For example, academics have often given importance to factors related to social capital, to analyze the degree of interaction (with other farmers, with agricultural extension agents, local leaders, or institutional representatives, among others). Other studies, also based on multivariate approaches, have integrated characteristics such as farm size, economic performance, and level of education (including the ability to access information). Furthermore, a considerable number of studies include the variables of the perception of potential adopters, where risk aversion, relative advantages, complexity of use of innovations and uncertainty are analyzed. In this sense, studies based on behavioral theories have been useful to clarify that perception is related to many complex variables, but it is frequently demonstrated that lack of confidence due to the complexity of use (lack of training in the adoption of agricultural practices), economic risk aversion (due to lack of knowledge of the relative advantages) and low cooperation between actors and institutions (related to social capital), are factors that limit the adoption of practices, having a pernicious effect on both economic and environmental advantages.

Finally, the bibliographic-documentary review presented here offers to the scientific community a reference on different theoretical-conceptual and methodological approaches that constitute the starting point for their practical application in research on the processes of diffusion and adoption of innovations in agriculture. In this practical application, researchers tend to use more and more diverse and complementary conceptual bases and methodological approaches. For this reason, attempting to make a precise, differentiated delimitation that does not take into account such conceptual and methodological complementarities would be not only complex but, more importantly, probably inadequate. It should be understood that the different overlaps between research trends constitute, despite the complexity that this entails when carrying out bibliometric reviews such as this one, an enormous scientific wealth, a clear sign of the vitality that research on the processes of diffusion and adoption of innovations in agriculture has achieved. From here, for those more interested in the global issue of diffusion of innovations, or in any of the schools or trends defined through the co-citation and coupling analysis we have carried out here, a next step, focused on a more in-depth comprehensive literature review, would be necessary

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