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A Look at the Past, Present and Future Research Trends of Artificial Intelligence in Agriculture

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Abstract: Technification in agriculture has resulted in the inclusion of more efficient companies that have evolved into a more complex sector focused on production and quality. Artificial intelligence, one of the relevant areas of technology, is transforming the agriculture sector by reducing the consumption and use of resources. This research uses a bibliometric methodology and a fractional counting method of clustering to analyze the scientific literature on the topic, reviewing 2629 related documents recorded on the Web of Science and Scopus databases. The study found significant results regarding the most relevant and prolific authors (Hoogenboom), supporting research organizations (National Natural Science Foundation of China) and countries (U.S., China, India, or Iran). The identification of leaders in this field gives researchers new possibilities for new lines of research based on previous studies. An in-depth examination of authors' keywords identified different clusters and trends linking Artificial Intelligence and green economy, sustainable development, climate change, and the environment.

Keywords: artificial intelligence; agriculture; bibliometric analysis; cross world research

1. Introduction

Artificial Intelligence, hereinafter AI, is one of the disruptive technologies that has changed processes and developments in the field of science, technology, and business in recent years. The development of AI has resulted in streams of research: the analysis of events and their correlation over time, and the search for relationships between phenomena that may cause general deductive or inferential rules. In both cases, this research aims to explain past episodes and predict future events.

AI began in the 1950s, demonstrating that a new form of computing was possible, with an approach derived from known cognitive processes and from neurobiology. The initial purpose of the AI was to automate, through computers, non-analytical human knowledge, from symbolic computation processes, connectionist ones, or a combination of both. Although initially considered a branch of computer sciences with limited application and restricted by the capabilities of the hardware of the time, AI has since evolved into a vital element for the development of many services and industrial sectors in the 21st century.

AI is a discipline of computer science that studies algorithms to develop computer solutions that copy the cognitive, physiological, or evolutionary phenomena of nature and human beings. Unlike the traditional model, it does not require knowledge of specific paths to the resolution of problems. Rather, it is the data, examples of solutions, or relationships between these that facilitate the

resolution of diverse problems. AI exhibits, in certain aspects, "an intelligent behavior" that can be confused with that of a human expert in the development of certain tasks [1].

At present, AI has been redirected, following the definition of double analysis previously mentioned, towards the construction of solutions to problems with large volumes of data which change over time. This type of data can present inaccuracies and, in some cases, contradictions. Currently, the systems for approaching functions using iterative techniques, and the neural network architectures interconnected with each other, make up most of the techniques, which are grouped under the terms "Machine Learning" and "Deep Learning". The field of application for AI has been extended, having as a common denominator the analysis of large volumes of data or complex data structures which are dependent on time and unknown factors.

Agriculture is a sector that includes studies in science, engineering, and its economic derivatives. AI has not neglected this sector and there are numerous studies that have focused on it. McKinion and Lemmon and Murase [2,3] make comprehensive reviews of the use of deductive techniques based on expert systems in the field of agriculture. Other works highlight the applications of expert systems and decision support systems for the simulation of processes and the management of supply operations [4–6].

In other studies, AI has been used in quality control processes, whether or not they are supported by artificial vision, as in the case of Nair and Mohandas [7], or in processes of justification of food policy decisions, such as the case study by Bryceson and Slaughter [8], where the use of AI is analyzed as a collaborative tool between the different actors that supply the agri-food chain, using distributed computing processes.

Some studies investigate the price behavior of agri-food products [9–14]. In these cases, artificial neural networks and machine learning techniques are applied to limit the price variations of these commodities. In the field of science, aspects of climate are studied by Hewitson and Crane [15] and Mellit [16], who try to model and predict solar radiation using neural networks.

Interest in the application of AI to the world of agriculture and its multiple facets has been growing in recent years as it has proven to be a powerful tool for data analysis.

The expansion and intensification of industrial and technological agriculture have increased production, lowering the number of people suffering from poor nutrition and meeting the increased demand for richer and more resource-intense diets. Industrial agricultural activities also generate employment, improve economic growth, and boost the service sector in industrial regions [17].

Agriculture 3.0 brought robotics and automation to the agricultural world, as evidenced by agricultural machinery that performs complete cycles of agricultural work such as planting, spraying, and harvesting [18–20]. Now, it is the turn of agriculture 4.0, which, along with intelligent farms and the interconnection of machines and systems, seeks to adapt production ecosystems by optimizing the use of water, fertilizers, and phytosanitary products, giving rise to what is known as precision agriculture [21–23]. Combined with genetic engineering and the use of data, it can solve an important part of agriculture by maximizing efficiency in the use of resources and adapting to climate change and other challenges. To this end, the use of big data in decision-making is essential [24,25]. The technification of agriculture and the inclusion of concepts of Industry 4.0 by agri-food companies has also generated greater interest in AI.

At the same time, bibliometric studies that connect the different disciplines are of growing interest in the analysis of the impact of these synergies and their future within the research community. In general, bibliometric studies are of great interest to academia, as it is a clear indicator of interest in a particular field. An example of this is the paper by Gu [26], which shows the structure and model of the scientific production of researchers worldwide and the relationships between quality, references, and synergies among authors.

More specifically, in the field of AI, the work of Cobo et al. [27] analyzes its evolution through various bibliometric indicators based on citations of scientific production related to knowledge-based systems. Similar studies related to the agri-food industry or agriculture are not as common, nor are they as documented. However, the growth of interest in both fields is palpable.

Thus, the number of publications related to these two fields continues to grow. In Google Scholar, for example, there has been a sustained increase in the number of publications in the last five years, which leads us to think that this synergy will be maintained, and interest in studying the implications of one of these disciplines in another will be relevant in the short and medium term.

This work is a formal study of the scientific production of these lines of research, revealing the importance that this synergy currently has for the scientific community. A content analysis was carried out using two databases—WoS and Scopus—to determine the volume of publications, the scientific journals in which they are published, the most relevant researchers from the point of view of the quality of their publications and the volume of these, as well as a study of the geographical origin of these works to determine the interest in these issues at a global level.

2. Materials and Methods

To analyze the evolution of AI in the agricultural industry in scientific publications, a bibliometric analysis was carried out. This study is based on a systematic bibliographical analysis of the literature related to a central topic, following a sequence of steps [28]: (a) definition of the search criteria, keywords, and time; (b) selection of databases; (c) adjustment of research criteria; (d) full export of results; (e) analysis and discussion of results (Figure 1).

Two terms, "Artificial Intelligence" and "agric*", were selected for this research, and were focused on papers published until 2019. The quotation marks were used to retrieve correct and exact expressions, while the asterisk was used in "agric*" to retrieve all potential derivatives of the words. Therefore, "agric" is used as the root term of many expressions, such as "agriculture", "agricultural", "agriculturist", and "agriculturalist". Following this, publications from robust and reliable databases were identified. Garfield [29] first described a citation index for science. Two online databases were selected for this work: the publication of indexes in the Web of Science (WoS) Core Collection and Scopus. These are the most frequently used databases and both are multidisciplinary, recording scientific articles, reviews, and books, but also other documents such as meetings, proceedings, editorials, and letters. In addition, these databases provide access to the full texts of the documents.

The preliminary results of this search, without the application of filters, retrieved 3155 documents in Scopus and 586 documents in WoS. These results were adjusted and subsequently filtered, redefining the date until 2019. After collecting the documents including the selected terms for this research (in the title, keywords, and/or abstract), the results were checked one by one in order to verify their relevance to the objectives of this study. After debugging the databases, the initial query of these terms in the titles, abstracts, and keywords resulted in 2629 documents in Scopus and 438 in WoS, including articles, proceedings papers, reviews, editorial materials, book chapters, notes, software reviews, and letters.

After obtaining the final results, the data were exported into ".txt" format. For the analysis and discussion of the results, this research considered: number of annual publications and citations, languages, countries, journals, organizations publishing and entities funding research on this topic, and trends.

Bibliometric analyses are based on two criteria: the scientific publication, as an indicator of research output [30], and citations, as a proxy of their scientific impact [31]. Therefore, different bibliometric indicators were used in this analysis: impact of papers, based on the number of citations; and frequency, through the Hirsch index (h-index and averages), proposed by Hirsch [32] and defined as the number of papers with citation number $\geq$ h.
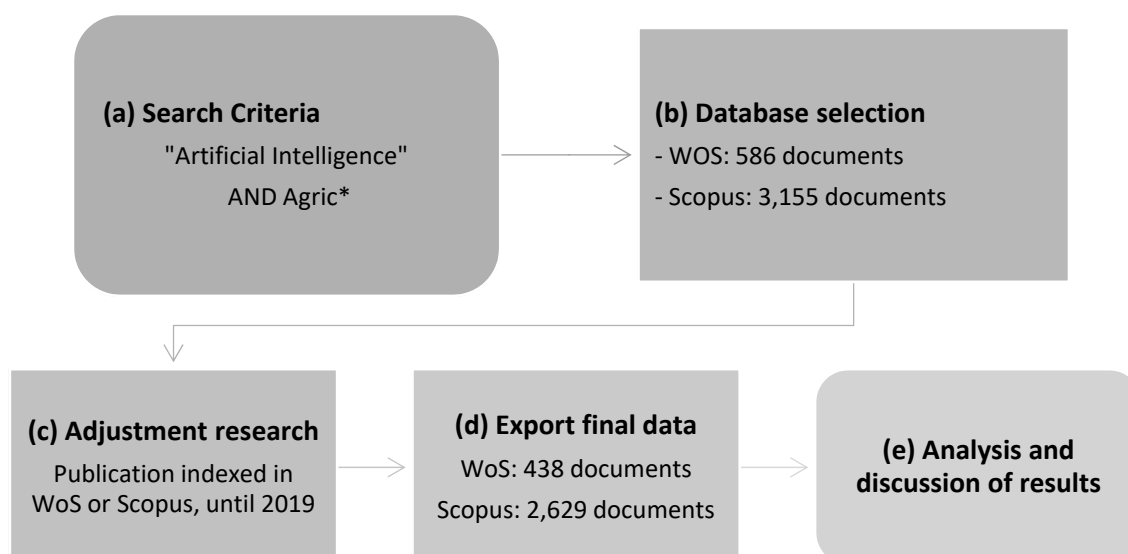
Figure 1. Stages of bibliometric analysis.

3. Discussion of Results

The use of AI in agriculture is an increasingly widespread phenomenon, encompassing different areas of the sector and linked, therefore, to multiple topics. Thus, to ensure that this research, focused on scientific publications, is as complete as possible and can cover all these related fields, the following keywords have been used in the search: "artificial intelligence" and "agric*".

In this research, the following elements have been analyzed: the annual evolution of the volume of publications and citations, the most influential countries in publications related to this field, the most outstanding journals, the most relevant authors, the most prolific universities related to these topics, the main entities supporting these publications, the main areas of knowledge involved, as well as the trends and terms that indicate future lines of research.

3.1. Evolution in the Number of Publications per Year

Research on the use of AI in agriculture is relatively recent. The first publication is from 1976 (Scopus), with the Proceedings of the IEEE Conference on Decision and Control, which took place in Florida (U.S.) [33]. In WoS, there are no publications on this topic until 1989, with the following two articles: "Some lessons for Artificial-Intelligence and agricultural systems simulation" [34]; and "Agassistant—An Artificial-Intelligence system for discovering patterns in agricultural knowledge and creating diagnostic advisory systems" [35].

In addition, during the first few years, there was hardly any scientific production in this field. Figure 2 shows the historical evolution of publications including the terms "artificial intelligence" and "agric*" in the title, abstract, or keywords in the WoS and Scopus databases. In 2003 and 2004, there was a certain takeoff in the volume of publications, although it is not until 2005 when the first turning point is appreciated, with a significant increase in the number of scientific works. This notwithstanding, it has only been in the last decade that the interest in this topic has acquired greater relevance and the number of investigations has grown significantly, with figures that surpass 200 annual documents in Scopus. The significant growth in 2019 is quite notable, reaching 489 publications (Scopus), which clearly shows the interest that this field currently has among the scientific community.

A similar evolution to that of the volume of publications is observed in the number of citations per year, although with slight differences. Thus, the highest figures are in recent years, particularly

in the 21st century, with several years showing more than 1000 annual citations. The highest number of citations (2743) is in 2017 (Figure 3).
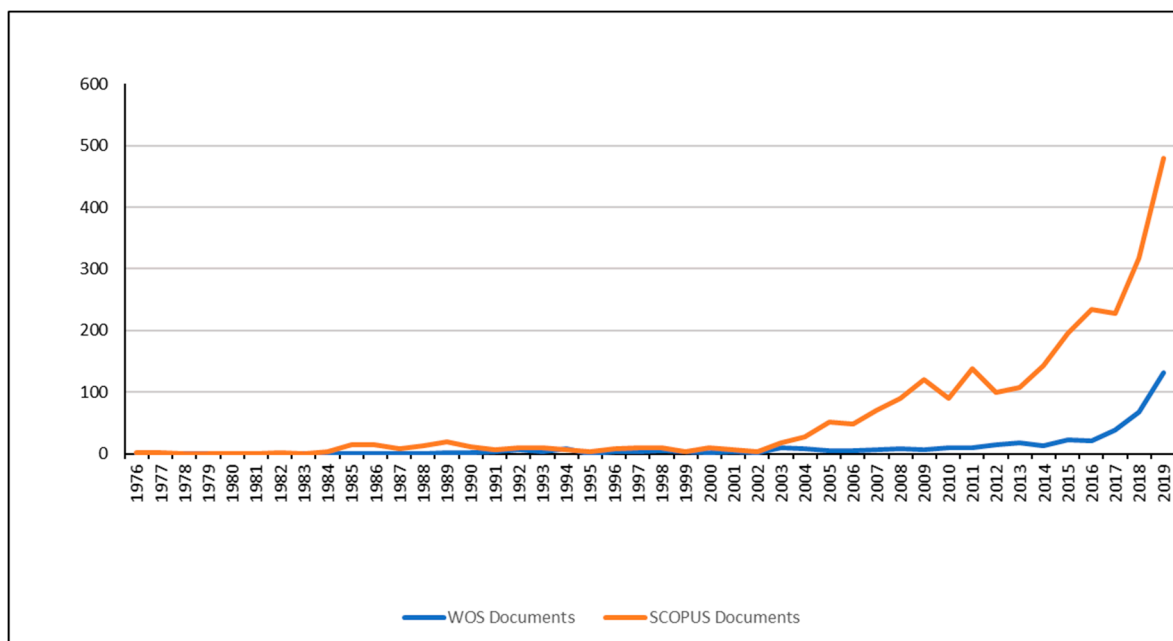
Figure 2. Annual evolution of publications.
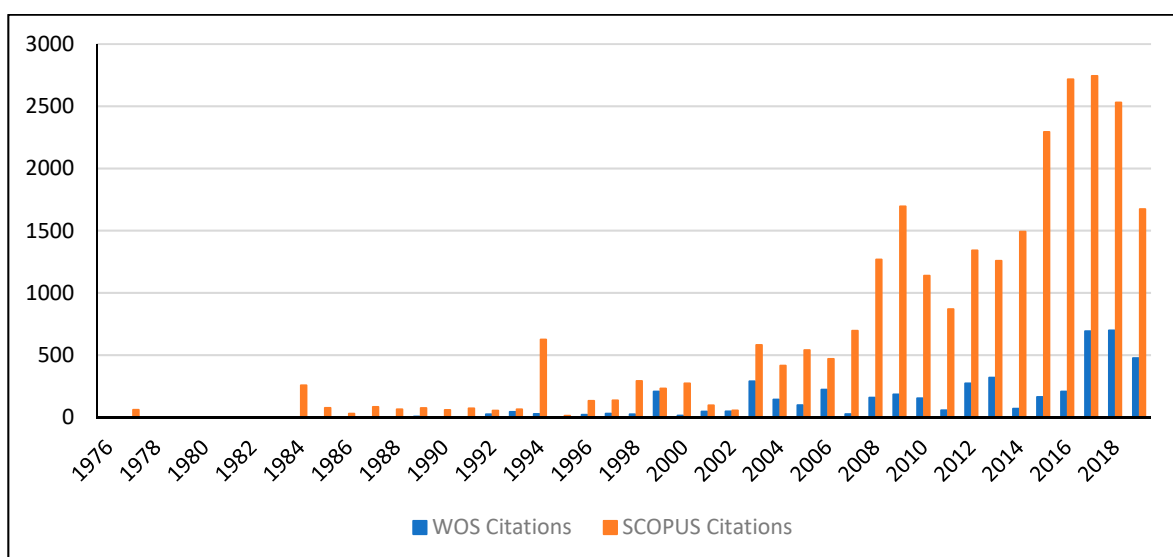
Figure 3. Number of citations per year.

3.2. Most Influential Countries

China is the most influential country in AI in agriculture (Scopus), with 489 publications, closely followed by the U.S., with 449 publications. India is in third place, with 291 publications. These three countries account for 47% of the total publications in Scopus in this field (Table 1). The importance that this topic has in these countries could be one of the main reasons why they occupy this privileged position in the ranking, showing a clear commitment to improving the profitability and efficiency of the agricultural sector. A second group of influential countries consists of Spain (127 publications), Germany (106), Australia (105), and the U.K. (95). Finally, the role played by countries such as Iran, Malaysia, and Egypt, where agriculture represents a significant percentage of its economic activity, is also noteworthy.

When analyzing indicators such as h-index and total citations, the ranking undergoes some significant variations. In that scenario, the U.S. leads the ranking (h: 41; 6661 citations), followed by

China (26; 2882), Spain (25; 2370), and Italy (24; 2003). Italy also leads the indicator of citations per article, with an average of 24.43, which also shows its prominent role in this area of knowledge, as well as the importance of the sector in its economy and the level of development of AI in this field.

Table 1. Ranking of countries attending the number of publications and citations.

WOS					SCOPUS			
Country	P	C	C/P	h-i	P	C	TC/P	h-i
U.S.	67	1169	17.45	18	449	6661	14.83	41
China	64	507	7.92	13	489	2882	5.89	26
Iran	36	702	19.50	16	86	1342	23.96	21
India	32	311	9.72	7	291	2064	7.09	23
Brazil	26	155	5.96	5	87	693	7.97	14
U.K.	23	462	20.09	10	95	1482	15.60	19
Spain	21	270	12.86	7	127	2370	18.66	25
Germany	16	151	9.44	6	106	1471	13.88	21
Japan	16	87	5.44	4	62	531	8.56	12
Malaysia	14	225	16.07	9	51	590	11.57	16
Turkey	15	329	21.93	7	39	612	15.69	13
Australia	13	143	11.00	9	105	1459	13.90	21
Egypt	13	82	6.31	6	38	220	5.79	8
Italy	12	339	28.25	7	82	2003	24.43	24

P—total number of publications; C—total number of citations; C/P—average citations per publication; h-i—Hirsch index.

Although China dominates in terms of the number of publications on the topics analyzed in this research, the most frequent language of publication is English, representing 96.96%. Thus, this is the language most used on these issues by the most relevant journals.

3.3. Most Influential Journals

When analyzing the most influential journals publishing on issues related to the use of AI in agriculture, it is observed that there are numerous journals in different areas of knowledge. On the one hand, those mainly specialized in Information and Communications Technology (ICT) (such as computers, engineering, etc.) and on the other hand, those journals more focused on aspects such as agriculture, environment, resources management, hydrology, etc. This shows the importance of this topic, which arouses interest in different fields, as it is a cross-cutting issue, resulting from the combination of several areas of knowledge.

As shown in Tables 2 and 3, according to the h-index, Computers and Electronics in Agriculture is the most influential journal for AI in Agriculture (33 in Scopus; 8 in WoS). This ranking is followed by Agricultural Water Management (14) and Lecture Notes in Computer Science (9).

Likewise, Computers and Electronics in Agriculture leads the ranking of the volume of publications in both databases (137, Scopus; 25, WoS). The following journals with the largest number of publications are Lecture Notes in Computer Science (91) and Transactions of the Chinese Society of Agricultural Engineering (39). With regards to the number of citations, once again, Computers and Electronics in Agriculture occupies first place in the ranking, with 3643 citations. This journal is followed by Agricultural Water Management (713) and Lecture Notes in Computer Science (370).

Among the most relevant journals in this field, those with the greatest impact factor (taking into account the 2019 JCR index on WoS) are: Science of the Total Environment (6.551), Remote Sensing (4.509), and Agricultural Water Management (4.021).

Table 2. Journals and impact (WoS).

R	Journal	IF	P	C	C/P	h-i
1	Computers and Electronics in Agriculture	3.858	25	613	24.52	11
2	Science of the Total Environment	6.551	7	241	34.43	7
3	Sensors	3.275	6	184	30.67	4
4	Water Resources Management	2.924	6	123	20.50	5
5	Environmental Science and Pollution Research	3.056	5	17	3.40	2
6	Agricultural Water Management	4.021	4	87	21.75	4
7	Environmental Earth Science	2.180	4	82	20.5	3
8	Remote Sensing	4.509	4	44	11.00	3
9	Biosystem Engineering	3.215	4	37	9.25	4
10	IEEE Access	3.745	4	21	5.25	2

R—ranking; IF—JCR index 2019; P—total number of publications; C—total number of citations; C/P—average citations per publication; h-i—Hirsch index.

Table 3. Journals and impact (Scopus).

R	Journal	IF	P	C	C/P	h-i
1	Computers and Electronics in Agriculture	1.058	137	3,643	26.56	33
2	Lecture Notes in Computer Science	0.427	91	370	4.07	11
3	Nongye Gongcheng Xuebao Transact. of the Chinese Society of Agric. Eng.	0.438	39	230	5.90	10
4	IFIP Advances in Information and Communication Technology	0.209	38	74	1.95	4
5	Advances in Intelligent Systems and Computing	0.184	37	99	2.68	6
6	Agricultural Water Management	1.369	35	713	20.37	18
7	Intern. Archiv. of the Photogrammetry Remote Sensing and Spatial Inf. Science	0.367	28	73	2.61	4
8	Procedia Computer Science	0.342	21	230	10.95	7
9	Communications in Computer and Information Science	0.188	21	31	1.48	3
10	Paper American Society of Agricultural Engineers	0.177	18	20	1.11	2

R—ranking; IF—SJR index 2019; P—total number of publications; C—total number of citations; C/P—average citations per publication; h-i—Hirsch index.

3.4. Most Relevant Authors and Cited References

When studying the relevance of authors in a specific topic, bibliometric analysis can take into account several indicators. This work focused on two aspects: the volume of publications, which shows the involvement of the researcher in the field; and the impact of publications, with reference to the number of citations, that is, by counting the number of other papers referencing it.

With regards to the number of publications and h-index, according to the Scopus database (Table 4), Professor Gerrit Hoogenboom from the Department of Agricultural and Biological Engineering at the University of Florida (U.S.) is the most relevant author, since his 15 publications about this topic have 483 citations, having an h-index of nine. Some other relevant authors in this topic are: James W. Jones (13 publications, h-index of 58), Director of the Florida Climate Institute and Professor Emeritus in the Agricultural and Biological Engineering Department at the University of Florida (U.S.); Fu, Z. at Beijing Laboratory of Food Quality and Safety (China) (12 publications, h-index of 22); John R. Barret (9 publications, h-index of 6) and J.C. Ascough (8 publications, h-index of 29), both at the United States Department of Agriculture, Agricultural Research Service (U.S.).

Table 4. Most relevant authors (Scopus).

R	Author	P	C	C/P	h-i
1	Hoogenboom, G.	15	483	32.20	52
2	Jones, J.W.	13	209	16.07	58
3	Fu, Z.	12	41	3.41	22
4	Barrett, J.R.	9	14	1.55	6
5	Ascough, J.C.	8	71	8.87	29
6	He, Y.	7	106	15.14	55
7	Corrales, J.C.	7	18	2.57	10
8	Fraisse, C.W.	7	62	8.86	19
9	Thorp, K.R.	6	196	32.66	29
10	McClendon, R.W.	6	139	23.17	20
10	McMaster, G.S.	6	45	7.50	25

R—ranking; P—total number of publications; C—total number of citations; C/P—average citations per publication; h-i—author Hirsch index on Scopus.

According to the number of citations, "WEKA: A machine learning workbench" [36] leads the ranking with 578 citations. This research focuses on WEKA, a workbench that is intended to aid in the application of machine learning techniques to real-world problems, mainly those arising from agriculture. The second research with the highest number of citations is "Big Data in Smart Farming— A review" [37] published in Agricultural System. The third study (338) is "The regularized iteratively reweighted MAD method for change detection in multi- and hyperspectral data" [38]. This paper describes new extensions to the multivariate alteration detection (MAD) method for change detection in bi-temporal, multi-, and hypervariate data, and provides examples using SPOT High Resolution Visible data from an agricultural region in Kenya and a small rural area in Germany.

The next work with the highest number of citations (254) is "Colour and shape analysis techniques for weed detection in cereal fields" [39] with 224 citations and which deals with the development of near-ground image capture and processing techniques in order to detect broad leaf weeds in cereal crops, showing the potential of using image processing techniques to generate weed maps. Following this is the paper "Making computers think like people" [40]. In this research, fuzzy sets and fuzzy logic are qualitatively described, and the application of fuzzy concepts to expert systems and computer vision is also discussed. The sixth work with the highest number of citations (227) is "Application of ANN for reservoir inflow prediction and operation" [41], which analyzes the influence of the land use and the plant species in the waterbed on the water quality of a high-altitude wetland in India.

Finally, in order to understand the total strength of the co-authorship links with other authors, the minimum number of documents of an author was set at two articles. In total, 836 authors out of 5870 meet this threshold. For each of them, the total strength of the co-authorship links with other authors was calculated. Thus, the largest set of connected authors consists of 19 links. Some clusters may be highlighted, such as the one led by Hoogenboom, G. (pink color); Wang, L. and Zhang, X. (mustard color); Chen, X. and Li, Y. (green); Fu, Z. (brown); Wang, M. and Li, X. (red); Liu, X. (orange); Huang, Q. and Yu, X. (purple); and Wang, Y. and Liu, Y. (grey) (Figure 4).

Figure 4. Co-citation map based on bibliographic data.

3.5. Institutions and Funding Sponsors

There are several public and private institutions disseminating knowledge through research and scientific publications on AI in agriculture. The twelve most relevant institutions (Table 5) have produced 14.97% of the total publications on this topic. This ranking is clearly led by entities from China and the U.S. Six of the twelve main organizations are from China (China Agricultural University, Chinese Academy of Sciences, Ministry of Education China, Chinese Academy of Agricultural Sciences, Ministry of Agriculture of the People's Republic of China, and Zhejiang University), four from the U.S. (University of Florida, United States Department of Agriculture, Texas A&M University, and USDA Agricultural Research Service), one from Iran (University of Tehran), and there is also one from Europe, specifically from Spain (Consejo Superior de Investigaciones Científicas).

The institution with the largest volume of publications is China Agricultural University (CAU) (61 publications). CAU, from Beijing, is a Double First-Class University according to the Chinese Ministry of Education, specialized in agriculture, engineering, economics, management, and social sciences. However, taking into account the h-index and the number of citations, the institutions that lead the ranking are the University of Florida (UF) (h-index of 17; 1025 citations), University of Tehran (h-index of 16; 546 citations), United States Department of Agriculture (h-index of 9; 399 citations), and Chinese Academy of Sciences (h-index of 10; 459 citations). All these institutions are highly committed to AI research in the agricultural industry.

With regard to the U.S. entities, the University of Florida's Institute of Food and Agricultural Sciences (UF/IFAS) is a federal state–county partnership dedicated to "developing knowledge in agricultural, human and natural resources and making that knowledge accessible to sustain and enhance the quality of human life". It also has the UF-IFAS Space Agricultural and Biotechnology Research and Education (SABRE) Center and the Precision Agriculture Laboratory, focused on the development of agriculture through the use of ICT. The United States Department of Agriculture (USDA) provides support on food, agriculture, natural resources, rural development, nutrition, and related issues based on public policy. The National Institute of Food and Agriculture (NIFA) is part of the USDA, supporting AI activities through a variety of programs and areas: Agricultural Systems

and Engineering; Natural Resources and Environment; and Economics and Rural Communities. In addition, some subsections of the Agriculture and Food Research Initiative (AFRI) Foundational and Applied Science program provide funding in AI: Agriculture Systems and Technology; Bioenergy, Natural Resources, and Environment; and Agricultural Economics and Rural Community program areas.

The University of Tehran (Iran) has two main centers related to AI and agriculture: Faculty of Agricultural Science and Engineering; and Research in Artificial Intelligence, Robotics, and Information Science.

Another important indicator to understand the impact of the publications of an organization is the average number of citations, a ranking led by the Consejo Superior de Investigaciones Científicas (24.27) and the University of Florida (20.50), followed by the University of Tehran (16.54).

Table 5. Institutions promoting research (Scopus).

R	Institution	T	P	C	C/P	h-i
1	China Agricultural University	China	61	213	3.49	8
2	University of Florida	U.S.	50	1,025	20.50	17
3	Chinese Academy of Sciences	China	36	416	11.55	12
4	United States Department of Agriculture	U.S.	34	459	13.5	10
5	University of Tehran	Iran	33	546	16.54	16
6	USDA Agricultural Research Service	U.S.	30	345	11.50	10
7	Ministry of Education China	China	29	209	7.20	8
8	Ministry of Agriculture of the People's Republic of China	China	24	206	8.58	7
9	Texas A&M University	U.S.	23	235	10.21	8
10	Chinese Academy of Agricultural Sciences	China	20	259	12.95	7
11	Consejo Superior de Investigaciones Científicas	Spain	18	437	24.27	9
12	Zhejiang University	China	17	204	12.00	6

R—ranking; P—total number of publications; T—Territory. C—total number of citations; C/P—average citations per publication; h-i—Hirsch index.

With reference to funding agencies sponsoring research on AI in agriculture, the top ten is led by National Natural Science Foundation of China (65 publications) (Table 6). China occupies two of the top ten positions in this ranking, with the following entities also publishing research on this topic: National Basic Research Program of China (973 Program) (18 publications), promoted by the People's Republic of China to achieve technology in several scientific fields; National Science Foundation of China (NSFC) (65), an organization directly affiliated to China's State Council.

There is, therefore, an obvious commitment by the Chinese government to encourage and support Chinese universities and research centers to advance in studying the potential of AI in the agricultural industry. Being aware of the strong demand for AI, the Chinese government has planned a robust support system in education, research, and AI applications, and this becomes visible in the development of numerous plans that encourage research centers to apply AI to improve efficiency in agricultural production.

The U.S. is also relevant in this ranking, with three agencies in the top ten, one being the National Science Foundation (NSF) (24 publications), a government agency that supports fundamental research and education in all the non-medical fields of science and engineering. In some fields, such as mathematics, computer science, economics, and the social sciences, the NSF is the major source of federal backing; in addition, there is the U.S. Department of Agriculture (USDA) (20) and the National Institute of Food and Agriculture (NIFA) (15), which is also part of USDA. In the U.S., AI spending in agriculture industry increased at 66.0% during 2018, reaching USD 122.9 million.

Another relevant country is Brazil, with two agencies in this ranking: Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (20 publications) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (13), a public foundation for providing funds and programs to support research, education, and innovation of private and public institutions and companies. Finally, the European Commission (36) is the most important European entity supporting

research on AI in agriculture, having AI and robotics among its priorities, in order to put it at the service of European citizens and economy. The Commission has increased its annual investments in AI by 70% with the research and innovation program, Horizon 2020. It will reach EUR 1.5 billion by 2018–2020 [42].

Table 6. Funding agencies sponsoring research.

R	Funding Agencies	T	P
1	National Natural Science Foundation of China	China	65
2	European Commission	Europe	36
3	National Science Foundation	U.S.	24
3	Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)	Brasil	20
4	U.S. Department of Agriculture	U.S.	20
5	National Basic Research Program of China (973 Program)	China	18
6	National Institute of Food and Agriculture	U.S.	15
8	European Regional Development	Europe	14
9	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior	Brazil	13
10	Ministry of Science and Technology	Taiwan	13

R—ranking; T—territory; P—total number of publications.

3.6. Trends

Due to the transversal nature of the topics analyzed, there are a wide variety of fields dealing with them. Figure 5 shows a map based on bibliographic data on the co-occurrence of the authors' keywords by using a fractional counting method, which is useful to comprehend trends in the research.

This map also identifies the main interactions between the most frequent terms in this research, as well as the existing clusters. This cluster analysis showed 14 different groups, with 255 items. Thus, with reference to the map, academia is currently focused on terms such as: decision support system, machine learning, artificial intelligence, agriculture, precision agriculture, decision support systems, remote sensing, data mining, or image processing. These terms are grouped into clusters, such as: Decision Support System (expert system; Geographic Information System—GIS; evaluation); Machine Learning (sustainable development; image segmentation; land use; the normalized difference vegetation index—NDVI; weed detection); Agriculture (precision agriculture; fuzzy logic; Internet of Things; neural networks; sensors; cloud computing); Classification (computer vision; feature extraction; robot); Data mining (clustering) and Irrigation (Decision Support System for Agrotechnology Transfer—DSSAT; optimization). Due to the large amount of dates and potential technical difficulties to share the whole information, this information is available for readers upon request.

A trend map was also created using a fractional counting method based on bibliographic data on the co-occurrence of the authors' keywords. This map uses different colors to highlight the most commonly used authors' keywords in each of the last few years since 2011. In order to identify the most relevant trends, the most recent keywords are marked in yellow. Of the 1254 keywords, the minimum occurrences of a keyword was set at four. In total, 255 authors out of 4976 authors met this threshold. Figure 6 shows that current research on AI in agriculture is focused on topics such as: machine learning; Internet of things; deep learning; big data; sensors; cloud computing; drought; and robot.

Figure 5. Map based on the co-occurrence on the authors' keywords.

Figure 6. Map based on the co-occurrence on the authors' keywords, and evolution since 2010.

4. Conclusions

After many years of continuous growth and technification in agriculture, with more efficient companies, the two main concerns of the sector are focused on production and quality. This is due to the appearance of factors and concerns such as population growth, climate change, and food security. Therefore, the future of the sector involves advances in the application of technology developed in

various fields such as computer vision, Big Data, and AI, which engender the development of multiple companies dedicated to precision agriculture.

The use of AI in agriculture is a huge step forward for the sector, allowing it to enter a new stage of development since in addition, it can drastically reduce the consumption and use of resources. AI results in even more professional crop management, resulting in a more profitable and more sustainable agricultural sector.

In analyzing the historical evolution of publications about AI in agriculture, it can be observed that the first works are relatively recent. The oldest in Scopus is from 1976, with the publication of the proceedings of the IEEE Conference on Decision and Control. Given that the IEEE is one of the world's largest technical professional organizations dedicated to advancing technology for the benefit of humanity, the first publications began in engineering, computing, and technology information research and addressed agriculture as a relevant sector in which to develop numerous applications, thus covering the specific needs of this industry. This late start in publications on these topics is even more evident in WoS, a database in which the first works do not appear until 1989, with articles focused on using AI in agricultural systems simulation, and creating diagnostic advisory systems. During the initial years, there was little scientific production on these topics, and it was not until 2008 when the volume of publications reached higher values, as proof of the current scientific interest on this topic. Regarding the annual number of citations, the evolution is similar, with some slight differences.

China is the most influential country in AI in agriculture, in terms of the volume of publications, closely followed by the U.S. The three most prolific countries in this field (China, U.S., and India) represent 47% of all publications, an indication of the importance that these countries grant to improving the profitability and efficiency of the agricultural sector. There is a second group of influential countries, made up of Spain, Germany, Australia, and the U.K. Likewise, Italy leads in terms of the number of citations per article, which also shows the importance of this industry and the level of development of this field. Finally, there is another group of countries, such as Iran, Malaysia, and Egypt, in which agriculture plays an important role in their economies.

Since AI in agriculture is a very broad field, in which many areas of knowledge are involved, there are several journals publishing on this topic. On the one hand, there are journals directly related to technology, computers, engineering, etc. whilst, on the other hand, there are another group of journals related to agriculture, environment, resources management, hydrology, etc. This is a consequence of the cross-cutting character of this topic. Thus, according to their h-index, the most relevant journals are: Computers and Electronics in Agriculture (which also leads the volume of publications and the number of citations), Agricultural Water Management, and Lecture Notes in Computer Science.

In order to study the most relevant authors, this bibliometric research analyzes both quantitative (volume of publications) and qualitative indicators (number of citations). Thus, with reference to the number of publications and h-index, Professor Gerrit Hoogenboom is the most influential author, followed by J.W. Jones, Z. Fu, J.R. Barret, and J.C. Ascough. In order to understand the total strength of the co-authorship links with other authors, different clusters were also identified in this research. The publication with the highest number of citations is "WEKA: A machine learning workbench" [36], as the result of an international conference. Other papers with a high number of citations are "The regularized iteratively reweighted MAD method for change detection in multi- and hyperspectral data" [38] and "Colour and shape analysis techniques for weed detection in cereal fields" [39], published in the journal Computers and Electronics in Agriculture.

There are numerous public and private organizations with a high commitment to research on AI in the agricultural industry. This ranking is led by institutions from China (China Agricultural University, Chinese Academy of Sciences, Ministry of Education China, Chinese Academy of Agricultural Sciences, Ministry of Agriculture of the People's Republic of China, Zhejiang University) and the U.S. (United States Department of Agriculture, University of Florida, Texas A&M University). Other institutions such as the University of Tehran (Iran) and the Consejo Superior de Investigaciones Científicas (Spain) also have relevant positions.

In addition, many funding agencies support research in this field. Once again, China and the U.S. lead this ranking, in which Brazil and the European Union also play an important role. China's research on AI began later than the U.S. and Europe, but its development is rapid and intense, since the inclusion, in 1986, of AI Research and Development in basic research funding, mainly through two agencies: The National Natural Science Foundation of China (NSFC) and the National Basic Research Program of China (973 programs) for applied research. Thus, the Chinese government is promoting research related to AI, not only focused on the agriculture industry, but on various topics, such as: intelligent application systems, neural networks, human–computer interaction, computer vision, or genetic algorithms. Since 2000, the Chinese public administrations committed definitively to research AI, increasing funds destined to this research. Therefore, the Chinese institutions encourage and support Chinese research centers in order to identify the potential of AI in the agricultural industry and to apply it to production. Of note also is China's Ministry of Education's AI Innovation Action Plan for College and Universities, wherein more than 70 Chinese universities and colleges have introduced AI-related majors.

The U.S. is also relevant in this ranking, having been one of the leading pioneers in this field. Its current commitment to research on this topic is very high, with the funds allocated to it increasing significantly every year. Some of the most important American entities are the National Science Foundation, Department of Agriculture (USDA), and National Institute of Food and Agriculture (NIFA). Brazil also has two relevant entities supporting research on this field, one of them at the national level (Conselho Nacional de Desenvolvimento Científico e Tecnológico), and the other at a regional level (Fundação de Amparo à Pesquisa do Estado de São Paulo). Finally, the European Commission also has AI and robotics among its priorities under the research and innovation of the program Horizon 2020.

The use of AI in agriculture is quite transversal, with several areas of knowledge around this topic. By using a fractional counting method, based on bibliographic data on the co-occurrence of authors' keywords, this research identifies different clusters and trends: machine learning; Internet of things; deep learning; big data; sensors; cloud computing; drought; and robot. Other emergent lines of research are life cycle assessment (LCA), green economy, sustainable development, climate change, and the environment.

This research has some limitations, which may be the basis for future research. Some of them are related to the bibliometric analysis, a research method which is essentially quantitative in nature. However, completing it with a qualitative analysis is important to attain a better view of the research field analyzed. Some authors may be very influential in a specific field, even with only a few articles. The opposite can also happen, wherein a certain author with only one work published in the field analyzed may have a high number of citations. This is the reason why we not only consider the volume of publications, but also qualitative features and standardized metrics, such as the number of citations or the h-index. In any event, this methodology could be completed with other quantitative or qualitative tools (e.g., knowledge maps or visuals). It could also be of interest to implement a systematic literature review using other tools such as a meta-analysis.

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