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Trends in scientific research on precision farming in agriculture using science mapping method

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ABSTRACT

The article highlights the worldwide dissemination of precision agriculture scientific researches published from the period of 1996–2018, data gathered in the Scopus citation database, using the science mapping method. The findings show that there is a constant rise in the number of publications in precision agriculture. The USA is not only leading in the adoption of precision agriculture technologies but also in the publication of papers, accompanied by China placed in second place. The most frequent keywords highlighted the main topics authors concentrated on more, and the national affiliation of most cited papers was the USA. The main prominence and contributions of the results present scientific research trends in precision agriculture in the last two decades, and demonstrate the main countries, authors and organizations who have contributed, and were more productive in this area.

KEYWORDS

precision agriculture, trend analyses and forecast, network analyses, Scopus, bibliometrics

JEL CLASSIFICATION CODE

O3, Q16, I23

1. INTRODUCTION

In order to make better decisions related with crop production, precision agriculture practices information technologies to transport data from several sources, and it consists of three components: capturing data in an accurate manner, interpreting and evaluating the data, and execution of management part in a correct measure and time [1]. Since 1962 (based on the Scopus database) authors coming from different parts of the world have shown interest in writing papers in precision agriculture. It is an important innovative field of agriculture and more and more researchers from different universities have worked on this topic [2]. The publication of scientific articles started to rise after 1996, a period when the post-World War II period ended, and the area of technology and the big science officially started [3]. Hence, the purpose of this paper is to demonstrate the existing movements in research on precision agriculture area, considered as a new vital pattern for building a sustainable agriculture, digitizing agriculture, and highly helping farmers in their work [4].

There has been little research on the publication trends of scientific papers in precision agriculture areas. However, similar research was carried out in 2018. Pallottino et al. (2018)

analyzed the publication trends during the period from 2010 to 2016, presenting the Italian, EU and the world publication trends, using the science mapping approach [5]. Thus, we plan to examine the publication of scientific articles in a global basis, for a longer period starting from the period of 1996 until 2018 (current situation). The aim of this study is to explore the worldwide dissemination of precision agriculture researches published from 1996 to 2018.

After the introduction fragment, the literature review provides a general explanation of the theoretical background in precision agriculture and bibliometrics. The third section describes the materials and methods used for the analysis of this paper. The fourth section presents the results, which show descriptive statistics, the authorship patterns of the articles, and the most cited articles during the represented period.

2. LITERATURE REVIEW

2.1. Theoretical background

In the scientific literature, there are several definitions for precision agriculture. It is defined as: “The ability to handle variations in productivity within a field and maximize financial return, reduce waste and minimize the impact of the environment using automated data collection, documentation and utilization of such information for strategic farm management decisions through sensing and communication technology” [6]. Precision farming is predicted to have a positive impact on increasing farm output and creating sustainable agriculture around the world. According to the American Society of Agronomy (1989), sustainable agriculture refers to the enhancement of environmental quality and natural resources in a long term basis, offers humans the needed food nutrients, economically feasible, and improves the quality of life of farmers and society in general [7]. It enables farmers to save resources such as soil and water while reducing waste and environmental damages [8]. PA has caught the attention for establishing such changes since the early 1990s, where the urgent need for expanding farm production over the next 25 years on less land using less water assisting farmers to minimize costs and increase the productivity and profitability, at the same time protecting the environment [9].

Farmers are entering in a new area where the technology is predicted to facilitate the operations in the farm, and upsurge lucrativeness as a result of reduced costs. Precision agriculture is often termed as Precision Farming, Site-Specific Input Application, Site-specific Agricultural Technology or Variable-Rate Treatment [10]. Before the modern term “precision agriculture”, which has emerged from USA in 1980s and has been used since the early days of 1990s as the title of a Workshop in Great Falls, Montana, and still to these days, Site-Specific-Crop Management or Site-Specific Agriculture terms were used in the past [11]. Based on spatial and temporal variability in the field in order to obtain accurate information, precision agriculture delivers farmers with precise information regarding the overall processes and operations in the field. It allows farmers to make better

decisions on the distribution and timing of the fertilizers and other agrochemicals [12].

Precision agriculture has its roots since the initial days of agriculture, but its concerns were not the environmental issues, evidenced by the work of Gilbert and Lawes associated with precision agriculture, in which they wanted to examine the benefits of different crop nutrients and crop variations with the purpose to upsurge yields [13]. Nowadays, environmental impact has become an important dispute of precision agriculture. Smart farming technologies are an assortment of agriculture and computation is used nowadays to create a maintainable agriculture, thus the Internet of things and wireless networks are some of the subjects that are combined with agriculture to create smart farming in helping monitor decisions about irrigation, fertilizer, soil, and pests [14]. According to the Food and Agriculture Organization (FAO), the global and regional per capita food consumption has increased from 2,803 kcal/day (1997) to 2,940 kcal/day (2015) and is predicted to increase to 3,050 kcal/day by the year of 2030 [15]. The establishment of these smart farming machines has several benefits starting from an increase in efficiency and a reduction in environmental impacts [16]. Similarly, the use of water, pesticides, and fertilizers in developing countries is limited, whereas in developed countries they are overused to avoid the negative economic effects of nutrient deficiencies, thus applying the right amount of each input in the right time and place creates an environment without pollution and going towards sustainability target goals [17]. Higher adoption rates are mainly presented in developed countries such as United States, Germany, France, and Canada [18]. According to a study conducted in Southern US with cotton producers, the total adoption level of technologies in this region was 73.5%, and the most adopted precision farming technology was Global Positioning System-Guidance (GPSG) with 67% adoption level followed by Information Gathering (IG) with 40.9% adoption level, Automatic Section Control (ASC) with 29.3% adoption level, and Variable Rate Application (VRA) with 25.3% adoption level [19].

2.2. Bibliometrics

In the past, the first scientific papers were handwritten letters or books with no dignified style where the authors provided praises to previous work in the form of a letter, but with the development of science, the references were cited in the end of the text or in the footnote [20]. Citation analysis, an element of bibliometrics, studies the quantitative approach of citation model within literature, and investigates the quantity and impact of articles published by authors worldwide [21]. Bibliometrics, also known as scientometrics [22], is a method for evaluating the scientific work of individuals and organizations based on the number of papers published and its citation impact, where according to its fundamental hypothesis the more an article is cited, the higher is the impact and importance of that article [23]. Simultaneously, it deals with the application of quantitative measures relying on the bibliographic data which are originated in various scientific output categories such as books,



book chapters, conference proceedings, etc., and it is less relevant in those areas when the scientific journal is not the leading ambiance for representing research findings [24]. From 1920 until the 1950s, bibliometrics relied on manual methods, on small samples and was mainly used to manage and collect journals in libraries [25]. Consequently, it first appeared in print in 1969 [22], where Pritchard has defined bibliometrics as: “To shed light on the processes of written communication and of the nature and course of development of a discipline (in so far as this is displayed through written communication), by means of counting and analyzing the various facets of written communication” [26].

Bibliometric it is not a new idea, concept nor invention [23]. Its use has been expanded outside the social work ranging in different areas such as agriculture, the sciences, library, information science, technology, social sciences and medicine [21]. It firstly appeared hundred years ago, after the Second World War II (the period when the age of “the big science” legitimately commenced [3]) when the idea was to support the librarians in their daily work routine, and where the American chemist, Eugene Garfield during the 1950s started to assess scientific papers systematically based on their citations and literature used [23]. Nowadays, the majority of bibliometric research papers are based on the Science Citation Index (SCI) database, Web of Science database or Scopus database, giving access to thousands of articles. Bibliometric approach requires fewer costs and time comparing with peer-review approach, thus resulting to be more desirable by other researchers [27].

3. MATERIALS AND METHODS

This paper concentrates on the results of secondary data. The secondary data includes books, scientific papers, annual reports and other related publications that were created in this area. The sample used was attained from the Scopus database, where a total of 2,663 articles were retrieved published between 1996 and 2018. For creation of bibliometric data, visualization and analysis, VOSviewer software and Microsoft Excel Office 2016 were used.

3.1. The Scopus database

Bibliographic records associated with precision agriculture were reprocessed using the Scopus database for the period of 1996–2018. A total of 2,663 articles were retrieved from Scopus database to analyze the worldwide dissemination of precision agriculture researches published from 1996 to 2018. The period from 1996 to 2018 was chosen because the publication of papers related to precision agriculture started to rise in this period. Scopus is an abstract and citation database delivered by Elsevier, which encompasses various fields ranging from Agricultural and Biological Sciences, Biochemistry, Genetics, Medicine, and other topic areas [28], in contrast with Web of Science database, which provides articles only on natural sciences [29]. Similarly, it provides four search lines: a basic search line, an advanced search line, an affiliation search line and author search line

[28], and delivers more than 24,097,496 papers published [30] and over 21,000 peer-reviewed journals [29].

The Scopus search was conducted during 2018. In order to retrieve and then analyze the articles in precision agriculture, precision agriculture and smart farming keywords were used. These two keywords were combined to examine the 5,448 scientific articles. Most of the retrieved articles were in English language covering 92% of all retrieved scientific articles and only few of them were in French (0.6%), German (2.1%), Portuguese (1%), Czech (0.1%), Hungarian (0.2%), Chinese (3%) Russian (0.2%), Spanish (0.1%), Turkish (0.1%), Polish (0.1%), while only one paper was published in Croatian, Swedish, Norwegian, and Dutch each.

3.2. Bibliometric mapping

From a bibliometric point of view, the collaboration of authors or authors communities is not usually viewed or studied graphically, but described as a social factor, with a variety of factors, including economic factors and factors from many other areas of research. The general trend in the most influential scientific journals is an increase in activities, driven by collaboration between researchers and between research institutes and universities, in particular international co-authoring and citation networks [31].

Overall, co-authorship and citation networks can also be defined as social networks, but we must always keep in mind that co-authorship is a much stronger social bond than citation. A Citation Network (CN) is defined as a type of information network that represents a network of relatedness of an object [32]. CN is a special type of social network. Co-authorship analysis can be used to determine the author's position in the collaborative network. It can provide important information about scientists own contributions to research findings in their official scientific biographies. Together with the h-core analysis, this helps to clarify the extent of the researcher's actual contribution to the research findings they share and the citation effect achieved by these publications [33].

VOSviewer is a computer program used to create, display, and explore bibliometric maps of science [34]. The program is freely available at www.vosviewer.com. VOSviewer can be used to analyze all kinds of bibliometric network data, such as citation relationships in publications or journals, collaborative relationships between researchers, and co-occurrence relationships between scientific terms. In this report, we introduce the new text mining features in VOSviewer [34].

4. RESULTS AND DISCUSSION

4.1. Descriptive statistics

Since 1996 a great number of research articles were published by authors worldwide. Roughly 2,663 scientific articles were published from the year 1996 until 2018 based on the data from Scopus database. Correspondingly, the first scientific articles in precision agriculture area were published in fish industry, in French language during 1962, titled as:



“Étude de deux facteurs inhibant la production de *Tilapia melanopleura* Dum” and “La place des principes d'expérimentation en pisciculture” written by Gruber R. [35], decoded as “The two factors that prevents the production of *Tilapia Melanopleura dum*”, and “The place of experimental principles in fish farming”.

Nevertheless, a total of 2,663 scientific articles were retrieved from the period of 1996–2018 using the Scopus database to analyze the dissemination of scientific articles published in the precision agriculture field.

Authors coming from different parts of the world have shown interest in writing papers in precision agriculture area. Since the day farmers began to apply the precision farming technologies in their farms, mainly in developed countries, the author's willingness to explore and examine their effectiveness started to be recognized. Similarly, during the period of 1996–2018, there has been a constant increase in the number of publications of scientific articles in precision agriculture area. It all started with 25 papers published in 1996 and ending with 272 papers in 2018 (Fig. 1). In 1996, authors were more interested in investigating these technologies in crop farming, as they began to be applied mostly in this industry. This is proven by the focus of articles published in those days. According to the Scopus database, authors have elaborated on various topics. They wrote about satellites, computers, and conducted soil tests to examine the protection of the groundwater. Similarly, they wrote about Global Positioning

System (GPS) system irrigation approaches, automatic field machine technology, sensing techniques, Geographic Information System (GIS) approaches, and many other significant issues related to precision agriculture area. Currently, precision farming technologies have begun its use also in livestock, which is demonstrated by the topics of articles published at the present time, where authors analyzed the environmental impacts of livestock precision farming and similar disputes. Similarly, the number of publications increased to 247 more papers in 2018, where the total number of articles published stands at 272 today. The highest number of papers was published in 2017, accounting for 292 published papers.

Based on the results, 56% were articles, 34.5% were conference paper, 4.2% reviews, 3.3% were book chapters, and others were conference review, short survey, note, editorial, and books (Fig. 2).

4.2. Authorship patterns of the articles

From the moment these technologies were introduced to the market, the question was how effective, accurate and sustainable they were? As farmers began to adopt them, a vast number of authors began collecting data and reporting their overall economic and environmental impact, as a result. The most of international and European conferences that were held until now, focused on precision agriculture area, covered different topics but the main specific issues were auto-guidance systems, and variable rate nitrogen and lime

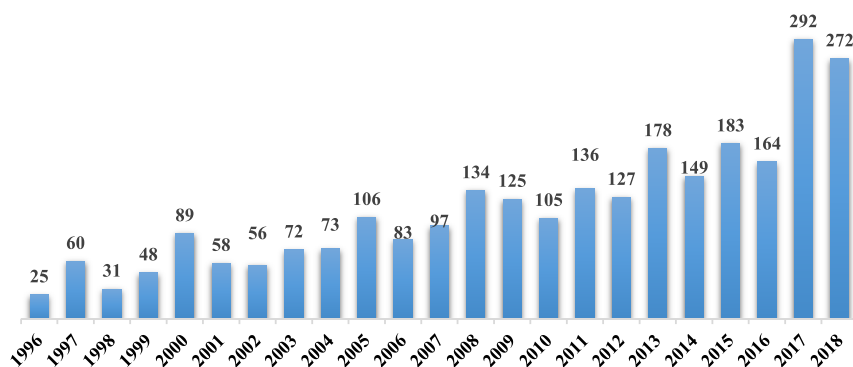


Fig. 1. The number of scientific articles published in the examined period.

Source: Author's own construction

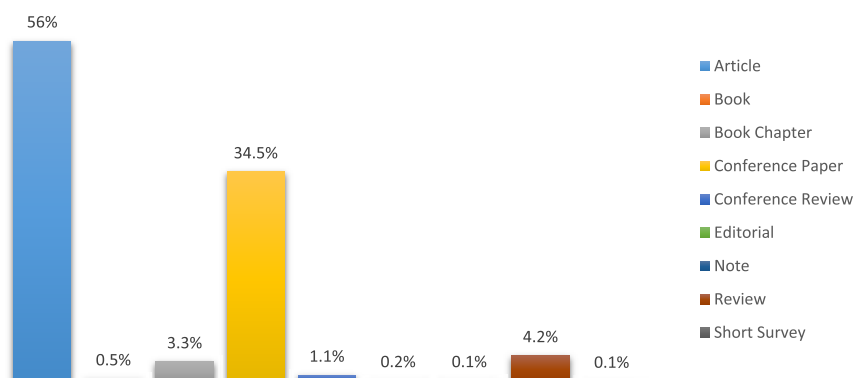


Fig. 2. Type of documents published in precision agriculture area.

Source: Author's own construction

applications and irrigation systems [10]. Articles retrieved from Scopus database are published by different publishing companies. Consequently, 10.6% of papers are published by Elsevier, 5.9% are published by Institute of Electrical and Electronics Engineers Inc., 2.4% are published Molecular Diversity Preservation International and Multidisciplinary Digital Publishing Institute (MDPI Ag), 2.3% are published by American Society of Agricultural and Biological Engineers, and the 42.8 % other papers are published by different publishers. On the other hand, in 36% of papers, the publisher is not mentioned or missing.

In Fig. 3 the size of the nodes represents the number of documents published by countries worldwide, the thickness of the lines represents the number of co-operations. The different colors show clusters that can be easily separated in the co-authoring network.

Despite being a leader in Asia-Pacific in the application of precision farming technologies [18], China is also leading in the research area after the USA (Fig. 3). A total of 152 countries have contributed to the publication of papers in the precision agriculture field. United States (22%; $N = 1,182$) and China (19%; $N = 1,023$) dominate in the publication of papers followed by Brazil (7%; $N = 392$), Spain (6%; $N = 313$), Germany (5%; $N = 296$), Australia (4%; $N = 212$), Italy (3%; $N = 191$) and others. Similar research was done in 2018 to analyze the distribution of scientific articles in precision agriculture using the science mapping approach, and based on the results the number of publications increased after 2006 with USA and China leading in the publication of scientific articles in precision agriculture (Table 1). Almost similar results were also shown in the mentioned article where

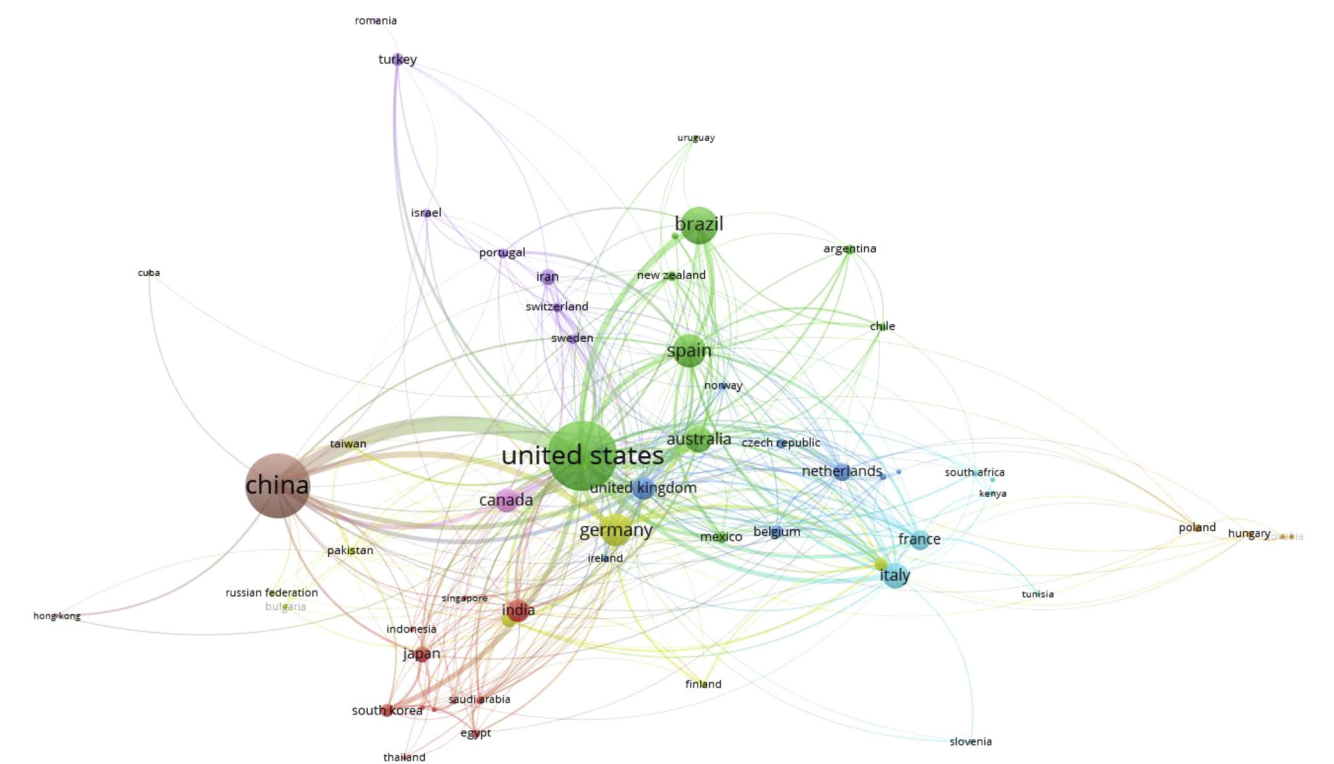


Fig. 3. Co-authorship network by country based on the world publication of precision agriculture.
Source: Author's own construction

Table 1. Top 10 countries with the highest publications in precision agriculture area

Country	Documents	Citations
United States	1,182	27,491
China	1,023	8,296
Brazil	392	3,153
Spain	313	5,422
Germany	296	5,346
Australia	212	5,406
Italy	191	2,809
Canada	174	4,960
India	156	918
United Kingdom	154	3,435

Source: Author's own construction.



according to their results the United States published 19.7% of publications, China 15.6%, and Germany 6.4% [5].

As the latest technological farming tool, it has drawn the attention of many researchers, particularly in the area of agriculture and engineering. Fig. 4 shows the co-authorship network. A total of 8,439 authors have contributed in publishing scientific papers in precision agriculture areas. The size of the nodes presents the number of articles published. The larger the node, the larger the number of documents published by the author. The color of the nodes presents the research groups.

Zhang Xiaoping (Research professor at Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences) is the most productive author accounting for 43 papers published in precision agriculture area, followed by Li Sam

Fong Yau (Professor at National University of Singapore) accounting for 42 papers, and Li Minglu (Professor at Shanghai Jiao Tong University) accounting for 41 papers. On the other hand, the author with the highest citations is Kenneth A. Sudduth (Researcher at USDA Agricultural Research Service) with 1,395 citations in total (Table 2).

The color of the node represents the average year the organizations published articles in precision agriculture. Purple color signifies organizations that have published in 2008 and earlier whereas the yellow color signifies organizations that have published in recent years, respectively in 2016 (Fig. 5). The organizations have published articles in precision agriculture area. Chinese organizations have shown a higher interest in writing articles in precision agriculture rather than organizations in other countries.

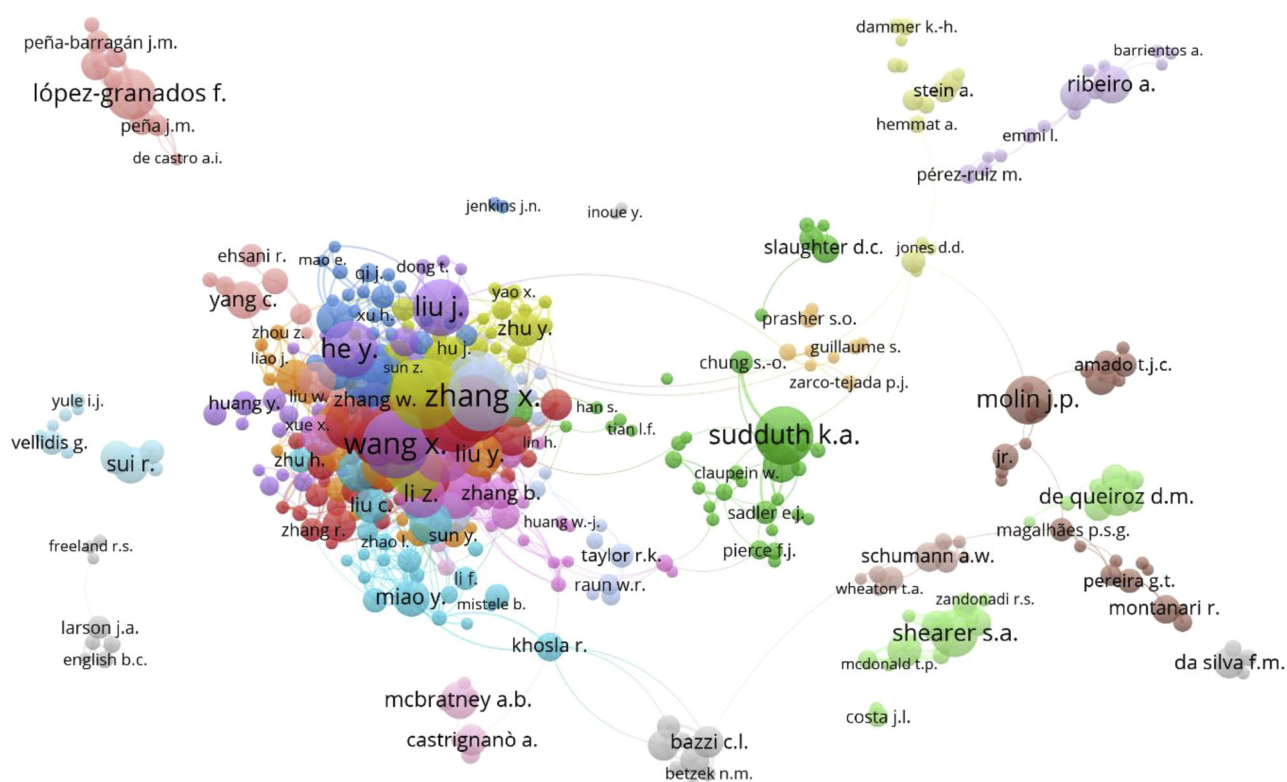


Fig. 4. Co-authorship network.
Source: Author's own construction

Table 2. Top 10 most productive authors in precision agriculture area

Author	Documents	Citations
Zhang x.	43	418
Li y.	42	356
Li m.	41	240
Wang y.	40	344
Wang x.	40	278
Zhang y.	39	483
Wang j.	38	304
Sudduth k.a.	34	1,395
Liu h.	32	258
He y.	32	293

Source: Author's own construction.

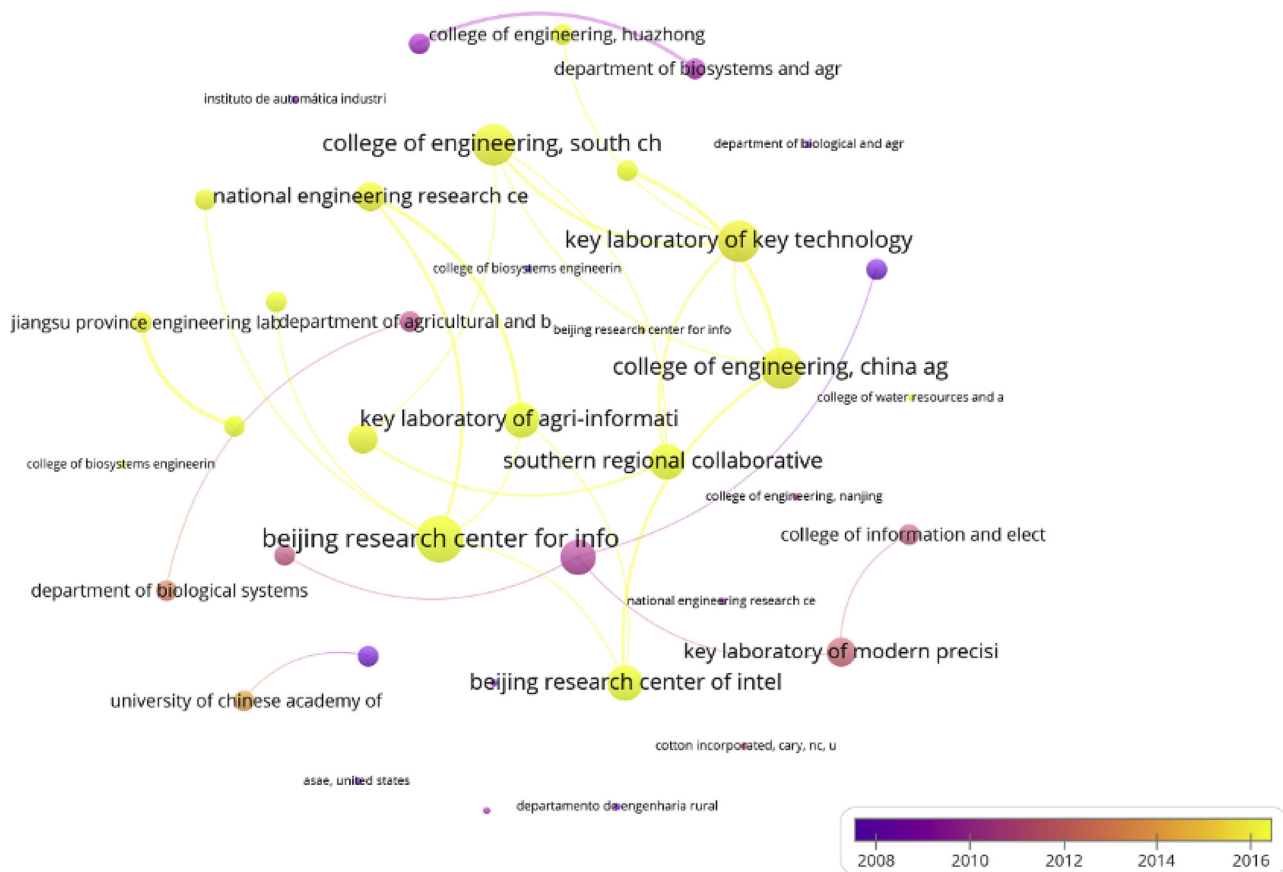


Fig. 5. Co-authorship network by organization. Author's own construction

More Chinese organizations in top 10 list shows not a higher interest, rather a wider (not so central) research work. As it is shown in Table 3, only one organization is located in the USA (Department of Biosystems and Agricultural Engineering, University of Kentucky) while the other ones are Chinese organizations. As a result, Beijing Research Center for Information, College of Engineering in Beijing, and College of Engineering in Nanjing have published the most articles in the precision agriculture area. Other organizations that have shown interest in precision agriculture are Key Laboratory of modern precision agriculture system integration research, College of Information and electrical engineering, National Engineering Research for Information Technology in Agriculture.

From the period of 1996–2018, a total of 14,171 keywords were used and presented from 2,663 articles retrieved from Scopus database. The color of a node designates the most frequently mentioned/used keywords during the represented period, where blue represents lower citation impact, red signifies average citation impact, and green, purple and yellow means higher citation impact. The keywords 'Remote sensing', 'soils', and 'crop yield' represent the most significant from the total keywords used in articles. Other keywords used are 'Zea mays', 'irrigation', 'cultivation', 'agronomy', 'nitrogen', 'crop production', 'soil moisture', 'United States', 'spatial variation', etc. In other words, these were the most important issues to many authors during the

inspected period of 1996–2018. Thus, most of the papers analyzed precision agriculture issues mainly in crops.

A variety of keywords were used in papers in precision agriculture (Fig. 6). Similarly, five key groups were identified: (red) a group connected to the terms 'sensor', 'cultivation', 'precision farming', and 'machinery', (purple) a group connected to the terms 'soils', 'sampling' and 'spatial variation'; (blue) a group connected to the terms 'methodology', 'chemistry', 'controlled and comparative study'; (green) a group connected to the terms 'crop yield', 'production', 'irrigation and soil moisture', and (yellow) a group connected to the terms 'remote sensing', 'vegetation and forestry'. The size of the nodes represents the number of connections they have. Bigger nodes represent the most relevant keywords in their group.

4.3. Most cited papers published between 1996 and 2018

Since the last forty years, thousands of studies have used information from citation indexes to deliver quantitative, qualitative and statistical analysis [36]. Citation analysis is an event that represents the use of the author's cited work and indicates the influence, knowledge from the cited work of authors and relatedness of the work cited [37]. It helps to avoid a lot of semantic problems that are found in terms and title analyses due to the replacement of the indexer's subjective judgment with the author's citations [38]. In 1998, it was

Table 3. Top 10 organizations with the highest number of published articles in precision agriculture area

Organizations	Documents	Citations
National engineering research center for information technology in agriculture, Beijing 100097, China	25	182
College of engineering, China agricultural university, Beijing, 100083, China	23	102
College of engineering, Nanjing agricultural university, Nanjing, 210031, China	16	44
key laboratory of modern precision agriculture system integration research, ministry of education, China agricultural university, Beijing 100083, China	16	98
College of information and electrical engineering, China agricultural university, Beijing, 100083, China	15	14
National engineering research center for information technology in agriculture, Beijing, 100097, China	14	44
Department of Biosystems and agricultural engineering, university of Kentucky, Lexington, KY, United States	12	123
Beijing research center for information technology in agriculture, Beijing, 100097, China	11	44
Key laboratory of key technology on agricultural machine and equipment, ministry of education, south China agricultural university, Guangzhou, 510642, China	11	56
Key laboratory of modern precision agriculture system integration research, ministry of education, China agricultural university, Beijing, 100083, China	11	47

Source: Author's construction.

used for the analysis of bibliographic citations of research papers in the academic library by graduate and undergraduate students where the findings indicated that the most used materials were from the library [39]. Likewise, in 2002, it was used to identify related collections of linked documents and the frequency between those documents [38].

Moreover, citation index is a list of cited articles published in scientific journals placed in an order [40]. The number of citations for all articles retrieved from the Scopus database in the precision farming area ranged from 1 to 553 citations. In Table 4, the most cited articles are shown, based on the data retrieved from the Scopus database. The article with the highest citation was published in 1997 titled "Opportunities and limitations for image-based remote sensing in precision crop management" by Moran M.S and Barnes E.M from USDA-ARS US. Water Conservation Laboratory, and Y. Inoue from NIAES Laboratory of Agrobiological Measurements in Japan. The most cited recent paper was in 2013 titled as "When yield gaps are poverty traps: The

paradigm of ecological intensification in African smallholder agriculture" written by Tittonell P. and Giller K.E.

The national affiliation for the first, third, seventh and eighth article in the USA, New Zealand for the second article, France for the fourth article, Netherlands for the fifth article, Italy for the sixth article, India for the ninth article and Canada for the tenth article. Likewise, most of the documents were articles except the first and ninth articles, which were review papers and the second article, which was conference paper (Table 4).

5. CONCLUSIONS

The results are presented from the total number of articles published in the precision agriculture area, based on the Scopus database. The VOSviewer software program was used to create, visualize and explore bibliometric maps of scientific articles in precision agriculture. The program is freely available



Table 4. Top 10 most cited articles in precision agriculture area between 1996 and 2018

	Author(s)	Title	Year	Cited by
1.	Moran M.S., Inoue Y., Barnes E.M.	Opportunities and limitations for image-based remote sensing in precision crop management	1997	553
2.	Di H.J., Cameron K.C.	Nitrate leaching in temperate agroecosystems: sources, factors, and mitigating strategies	2002	503
3.	Lal R.	Soil carbon dynamics in cropland and rangeland	2002	302
4.	Jacquemoud S., Bacour C., Poilvé H., Frangi J.-P.	Comparison of four radiative transfer models to simulate plant canopies reflectance: Direct and inverse mode	2000	288
5.	Tittonell P., Giller K.E.	When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture	2013	254
6.	Colombo R., Bellingeri D., Fasolini D., Marino C.M.	Retrieval of leaf area index in different vegetation types using high-resolution satellite data	2003	238
7.	Meyer G.E., Neto J.C.	Verification of color vegetation indices for automated crop imaging applications	2008	233
8.	Stone M.L., Solie J.B., Raun W.R., Whitney R.W., Taylor S.L., Ringer J.D.	Use of spectral radiance for correcting in-season fertilizer nitrogen deficiencies in winter wheat	1996	228
9.	Ghormade V., Deshpande M.V., Paknikar K.M.	Perspectives for nano-biotechnology enabled protection and nutrition of plants	2011	218

(continued)

Table 4. Continued

	Author(s)	Title	Year	Cited by
10.	MacMillan R.A., Pettapiece W.W., Nolan S.C., Goddard T.W.	A generic procedure for automatically segmenting landforms into landform elements using DEMs, heuristic rules and fuzzy logic	2000	209

Source: Author's own construction.

Consequently, these keywords may have generated articles that are not highly aligned with precision agriculture or precision technologies used in agriculture. Moreover, the number of articles retrieved from Scopus database is limited. Therefore, there may be other articles published in precision articles which were not retrieved from Scopus database as a result.

However, the main prominence and contributions of these results present scientific research trends in precision agriculture in the last two decades, and demonstrate the main countries, authors and organizations who have contributed, and were more productive in this area. Simultaneously, it presents the further research work in all topics that precision agriculture embraces. Current and future researchers may highlight issues such as: the number of authors in an article and co-authorship network, respectively, a network analysis of the relationship between authors.

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