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RURAL ENGINEERING

A bibliometric and scientometric analysis on the use of UAVs in agriculture, livestock and forestry

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ABSTRACT: The use of unmanned aerial vehicles (UAVs) in the agricultural and forestry sectors has constantly evolved due to its great versatility and applicability in the field. In this sense, this study provided a statistical overview of studies on the use of UAVs in agricultural and forestry through a bibliometric and scientometric analysis. For that, a research was carried out on the Scopus platform using the terms UAV, UAS, drone, and RPA, together with "agricult*" or "forest* or livestock". Only manuscripts published in English and from January 2000 to December 2020 were selected. The VOSviewer software was used for the analyses. The USA and China were responsible for more than 38% of the publications worldwide. Furthermore, about 50% of the countries in the world showed some scientific record of the use of UAVs in agricultural and forestry studies. The term UAS was more used until 2016, while UAV was more mentioned between 2017 and 2018. Conversely, drone was more endorsed from 2019. The constant increase in scientific production reported in the research and the evolution of the co-occurrence of keywords corroborated two ideas: i) the use of UAVs is still undergoing transformations and is directly related to the advancement of technology included in these equipments; and ii) studies are still not enough to explore all the applicability of the UAVs in agriculture, livestock and forestry.
Key words: drone, UAS, RPA, agricultural.

Uma análise bibliométrica e cientométrica sobre o uso de VANTs na agricultura, pecuária e silvicultura

RESUMO: A utilização de veículos aéreos não tripulados (VANTs) nos setores agrícola e florestal tem evoluído constantemente devido a sua grande versatilidade e aplicabilidade no campo. Nesse sentido, este trabalho teve como objetivo fornecer um panorama estatístico dos estudos sobre o uso de VANTs na agropecuária e silvicultura por meio de uma análise bibliométrica e cientométrica. Para isso, foi realizada uma pesquisa na plataforma Scopus utilizando os termos UAV, UAS, drone e RPA, juntamente com "agricult*" ou "forest* ou livestock". Foram selecionados apenas manuscritos publicados em inglês, de janeiro de 2000 a dezembro de 2020. O software VOSviewer foi utilizado para as análises. Os EUA e a China foram responsáveis por mais de 38% das publicações mundiais. Além disso, cerca de 50% dos países do mundo apresentaram algum registro científico do uso de VANTs em estudos agrícolas e florestais. O termo UAS foi mais utilizado até 2016, enquanto o UAV foi mais mencionado entre 2017 e 2018. Por outro lado, drone foi mais endossado a partir de 2019. O constante aumento da produção científica encontrado nas pesquisas e a evolução da coocorrência de palavras-chave corroboraram duas ideias: i) o uso de VANTs ainda está passando por transformações e está diretamente relacionado ao avanço da tecnologia inserida nesses equipamentos; e ii) os estudos ainda não são suficientes para explorar toda a aplicabilidade dos VANTs na agricultura, pecuária e silvicultura.
Palavras-chave: drone, UAS, RPA, agropecuária.

INTRODUCTION

Unmanned aerial vehicles (UAVs) refer to aircraft without any human pilot on board, which were first developed for military applications. Then, as technology evolved and their capabilities expanded, the UAVs were used in several civilian fields (MUCHIRI & KIMATHI, 2016). In developed countries, UAVs are already used in a diversity of applications since they are fast and can reduce the workload of humans. Applications include but are not limited to photogrammetry and remote sensing, forest inventories and fire monitoring, meteorological research, water management and use, animal tracking,

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in addition to mapping and image processing and precision agriculture (WONG, 2001; COLOMINA & MOLINA, 2014).

In agriculture, the first UAV model was an unmanned helicopter developed by Yamaha that was initially used for crop monitoring and pest control applications (MOGILI & DEEPAK, 2018). Currently, the applicability of UAVs is the most diverse, with crop and soil monitoring, pesticide spraying, and crop biophysical parameters estimation analysis being the most common (HUANG et al., 2009; BENDIG et al., 2012; PRIMICERIO et al., 2012; GILES & BILLING, 2015; MOGILI & DEEPAK, 2018). In the forest sector, accurate information on the composition, structure, volume, growth, and extent of the forest, which are essential for sustainable management, can be extracted directly or indirectly from images obtained remotely (SHAO, 2012; GAMBELLA et al., 2016).

According to the 'Agriculture in 2050' project, the world population is estimated to reach about 10 billion in 2050. Consequently, any techniques that increase the current agricultural production, while considering and reducing the impacts of this activity on the environment, will be beneficial to society (ZHANG & KOVACS, 2012). Smart farming can be used anywhere in the world and people who used to do traditional farming are becoming familiar with this technology when using UAVs since these types of equipment enable farmers to improve the production on smaller farms through the information that helps in the management of the agricultural production (KIM et al., 2019).

Since it is an equipment with technologies with huge and diversified potential, the use of UAVs in agricultural and forestry has constantly evolved and new applications are emerging every year. Understanding the transformation and development of UAVs can be important information to expand and explore all its applicability. For this, some techniques, such as bibliometric and scientometric analysis, have been used. However, the academic bibliography still lacks an in-depth bibliometric analysis of publications on unmanned aerial vehicles (KOTSEMIR, 2019).

In the literature, the term "bibliometry" was defined as "the application of mathematical and statistical methods to books and other communication media", and since then, it has been an effective tool for analyzing research trends in various fields of study (ZHANG et al., 2017). Meanwhile, "Scientometrics" is defined as the quantitative study of science, communication in science, and science policy and includes measuring the impact of research, investigating the impact of institutions and journals on a given field of research, and providing more insight into scientific citations (MARTINEZ et al., 2019). By using these two complementary techniques, it is expected to identify in this article authors, journals, countries, and their connections in published research that addressed the use of UAVs in the agricultural and forestry sectors.

Based on that, this study aimed to (1) provide a statistical overview of studies on the use of UAVs in agricultural and forestry applications by bibliometric and scientometric analysis and (2) to reveal the underlying patterns in scientific results, geographic distribution, general description of developments in this field of research, as well as the important issues of evolution in the period from 2000 to 2020.

MATERIALS AND METHODS

The Scopus platform was used for the bibliometric and scientometric research as it is the main source for evaluation of scientific production worldwide and due to its multidisciplinary and international coverage. Besides that, the Scopus platform was chosen because it is more complete than other platforms, such as the Web of Science. The latter does not has a system of unique author (and organization) profiles. In Scopus, a user can search for a particular organization (''affiliation'' in Scopus terminology) through thousands of organization profiles that were automatically formed by Scopus (VIEIRA & GOMES, 2009; KOTSEMIR & SHASHNOV, 2017).

The thesaurus was consulted to verify the most frequently used synonyms to refer to unmanned aerial vehicles, as well as the abbreviations for these terms, whose data collection was carried out on February 11th, 2021. Based on that, searches were performed for terms in the titles of articles, abstracts and keywords. The terms used in the research were "UAV*" (Unmanned Aerial Vehicle), "UAS*" (Unmanned Aircraft System), "drone*" and "RPA*" (Remotely Piloted Aircraft). In order to restrict the search to terms related to agricultural and forestry, such terms were used to limit the results to these areas of knowledge. The search was limited to publication records from January 2000 to December 2020. Only research and review articles restricted to the thematic areas "Environmental science" and "Agricultural and biological sciences", published in English, were selected. The search code was described as follows: (TITLE-ABS-KEY (uav*) OR TITLE-ABS-KEY (uas*) OR TITLE-ABS-KEY (drone*) OR TITLE-ABS-KEY (rpa*) AND TITLE-ABS-KEY (forest* OR agricult*

OR livestock)) AND PUBYEAR > 1999 AND PUBYEAR < 2021 AND (LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "ENVI")) AND (LIMIT-TO (LANGUAGE , "English")).

The logical sequence used in the bibliometric and scientometric analysis was divided as follows: i) data recovery; ii) extraction from the data network (download from database); iii) data normalization; and iv) visualization and analysis of thematic and connection maps (PETERS & VAN RAAN, 1993; NOYONS et al., 1999; BÖRNER et al., 2003; MORRIS & VAN DER VEER MARTENS, 2008).

The VOSviewer software (www.vosviewer.com) was used for mapping the connections between the bibliographic data (VAN ECK & WALTMAN, 2010). The dataset obtained from Scopus was uploaded on VOSviewer software. First, a ranking of relevance of the terms found in the pre-processing was performed and the clusters related to the research domain of the publications were analyzed (WALTMAN et al., 2010). Secondly, thematic maps of the connections between the bibliographic data were produced. In these maps, the size of the circular labels (or spheres) of an item is determined by its weight (A weight of an item should in some way indicate the importance of the item). The heavier an item, the larger its label. The color of an item is determined by the cluster the item belongs to. Moreover, the lines between items represent the connections. The stronger the connection between two items, the thicker the line used to display that connection on the map. The distance between two items in the visualization approximately indicates the relatedness of the journals in terms of co-citation links. In general, the closer two items are located to each other, the stronger their relatedness (VAN ECK & WALTMAN, 2020).

The years between 2015 and 2020 represented 81.5% of the total of publications and this period was used to quantify collaborations between countries. First, the majority of UAV - based publishing countries and scientific journals on agriculture, forestry and livestock was identified. To analyze the connections between countries or scientific journals, a co-authorship analysis was carried out by filtering a minimum number of five documents. For the analysis of keywords, a co-occurrence analysis was carried out using a minimum number of occurrence threshold equal to eight, *i.e.*, the number of times a keyword must be present in the dataset to be used in the analysis.

Networks of connections between keywords, authors, countries and journals were created using the VOSviewer software. Then, their interactions and evolution over the years were analyzed. In summary, the following methodologies were applied to reveal research patterns: keyword co-occurrence, co-authorship between authors, co-authorship between countries, citations between journals. For analysis and development of this step, the VOSviewer software was used. An overview of the proposed methodology is presented in figure 1.

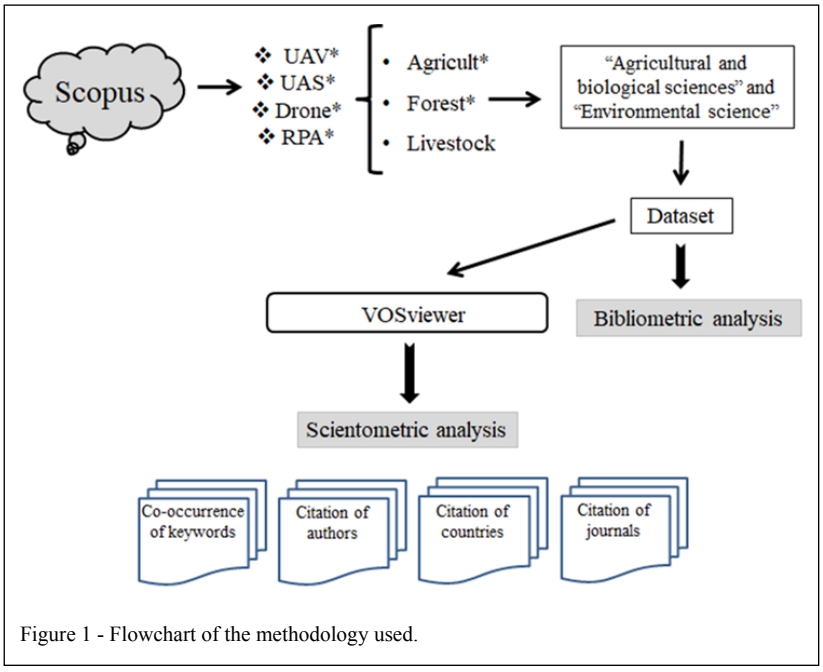

Figure 1 - Flowchart of the methodology used.

RESULTS

Data acquisition

Only publications in the form of research and review articles were analyzed, resulting in 1564 records for the studied period (2000-2020). All years within the research period presented at least one publication related to the topic (Figure 2). Although, it was observed in 2007 a considerable increase in the number of publications compared to the previous year, the years 2009 and 2010 showed a decrease in bibliographic production.

There was a trend of continuous increase in research involving UAVs from 2011, which shows the adoption of this technology as an interesting tool nowadays. From 2012, there has been an increase in publications of at least 20% per year. Furthermore, from 2016 to 2019, the increase in published documents was over 45%, showing an even greater trend in the use of technology in scientific research publications. Although, the year 2020 had a greater number of publications than 2019, the increase represented only 27% compared to the previous year. In this specific case, it must be considered that due to the COVID-19 pandemic, many studies and publications in the agricultural sciences were delayed and/or stopped.

The three countries with the greatest contribution in the number of publications were the United States of America (USA), China, and Spain (Figure 3). The USA and China accounted for more than 38% of the publications obtained in the survey, which may be related to the easiness of access to the technology since several UAV manufacturing companies are based in these countries.

A total of 103 countries have registered studies involving the use of UAVs, which represents over 50% of the countries in the world. In addition, more than 80% of publications were concentrated in the top-10 countries that publish the most. This information serve as an alert to show the discrepancy between countries regarding the technologies used in agriculture, forestry and livestock, as well as in the capacity to launch and establish high impact journals that are preferred for the dissemination of research.

Among the 1564 registrations used in this study, more than 5400 authors were reported. The Scopus platform considers all authors in a publication, which in some journals can configure multiple names. In this study, records with up to 25 authors were analyzed, in order to select more articles. Several authors presented ten or more records revealing that research with UAVs are the focus of study for several researchers. Zarco-Tejada, López-Granados, Zhang C., Torres-Sanchez and Peña J. were the authors with the highest number of citations in this study, which indicated their great importance in the applicability of UAVs in agricultural sciences studies (Figure 4).

Several journals stood out for the large amount of records in the area. The journals Computers and Electronics in Agriculture, Remote Sensing of the Environment, Forests, International Journal of Agricultural and Biological Engineering, Precision Agriculture, Plos One, Water Science and Technology, and Science of the Total Environment presented at least 20 documents published in the

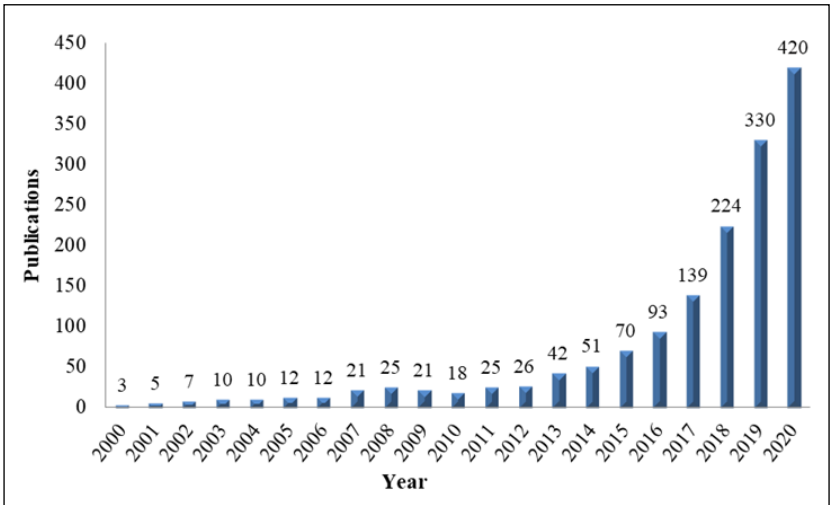

Figure 2 - Studies published in Scopus per year.

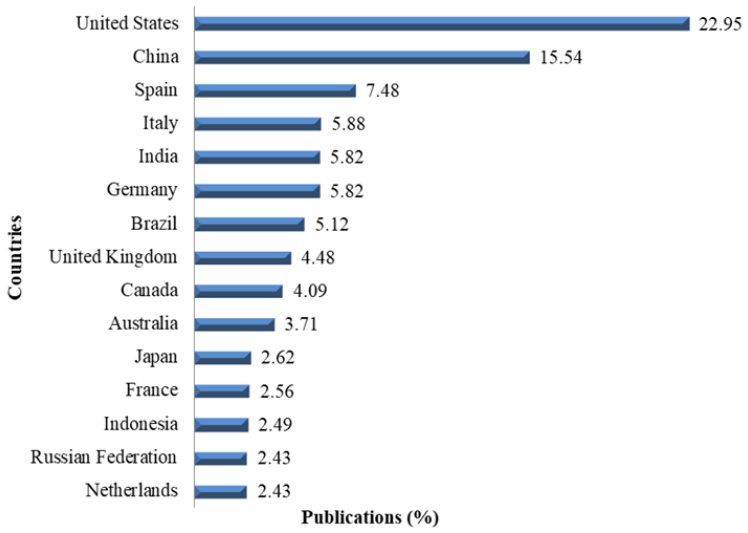

Figure 3 - Percentage of registrations from the top 15 countries in the Scopus platform.

last 20 years. In addition to these, there were other journals with at least 10 records between 2000 to 2020 (Figure 5).

Although, it is important to know the countries, authors and journals that have published the most articles in the area. The relationship and connections between these and the network of citations from these studies, allows a better understanding of the research lines and the transformations that the use of UAVs have provided in the agricultural sciences.

Analysis of the co-occurrence of key words

Keywords are used to target the main topics covered in a study and directly represent the content of publications. The co-occurrence network of keywords reported in this study became more complex from 2015 and gained more representation over the years, indicating that the number of publications over the years has been increasing (Figure 6). The VOSviewer tool allowed the visualization of the evolution of keywords used in research involving

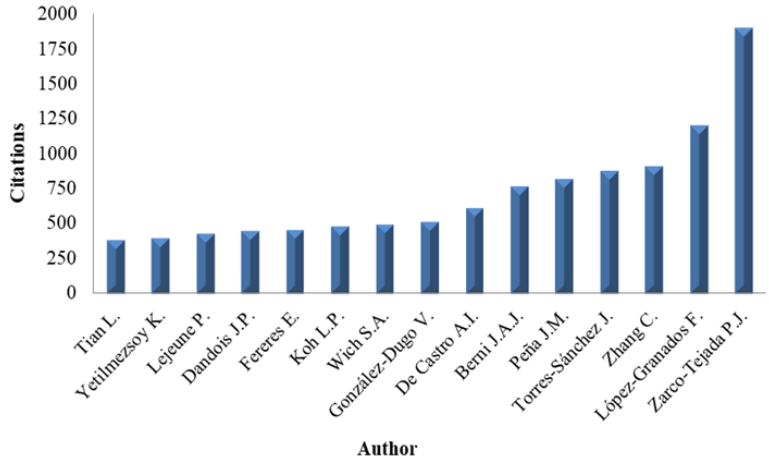

Figure 4 - Top 15 most-cited authors in the Scopus platform for the studied period (2000-2020).

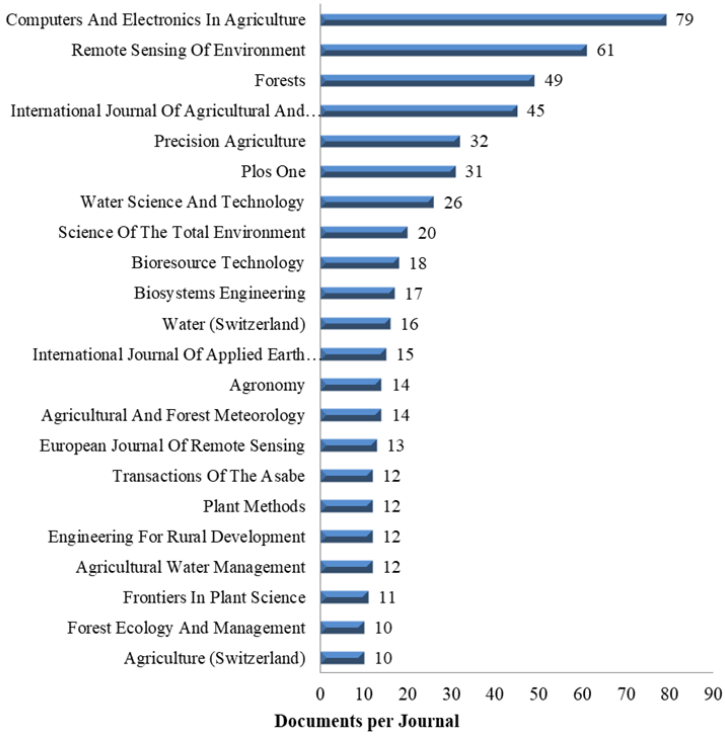

Figure 5 - Number of records on the Scopus platform by journals with at least 10 publications in the studied period (2000-2020).

UAVs. The terms tracking, navigation, location, aircraft, computer vision, identification, and irrigation were very common at the beginning of the studied period, indicating a certain limitation in the UAVs applicability until 2015.

In the last years, new technologies were incorporated into the UAVs and the variability of research using these artifacts became more comprehensive. Studies characterized by terms such as vegetation index, forest inventory, biomass, production, plant height and thermal images were more studied between 2016 and 2017. In 2018 and 2019, it was possible to identify a research trend in the areas of image processing, chlorophyll, conservation, photogrammetry, NDVI, and precision agriculture. More recently, the most discussed terms were aerial spraying, handling, aerial monitoring, sensors, crop canopy, crop management, prediction models, and yield prediction.

In addition to the evolution of applications of UAVs in research, it was also possible to identify the terminology most used in the studies. UAS was more used until 2016, while UAV was more mentioned between 2017 and 2018. Conversely, drone was more endorsed from 2019. Such transformations in a short time indicated that there is still no definition for the nomenclature of the technology.

Analysis of citations between authors

In order to verify the network connection between the authors' citations, a map was generated considering only authors with a production greater than 5 articles and at least 50 citations. The map created allowed to identify groupings between authors, being identified by the smallest distances between the spheres. Authors who are represented by the same color were most cited in the same period. When authors are placed closer to the core of the network and arranged with several connections, they indicate greater diversification in terms of citations in their research. Conversely, when authors are further away from the networks' core, it is possible to see that there is less heterogeneity in their citations.

Although, Zarco-Tejada was the fourth author with the largest number of publications among those selected, this author was the most cited among all others and has a wide network of connections with several others. In addition, Lopez-Granados, the

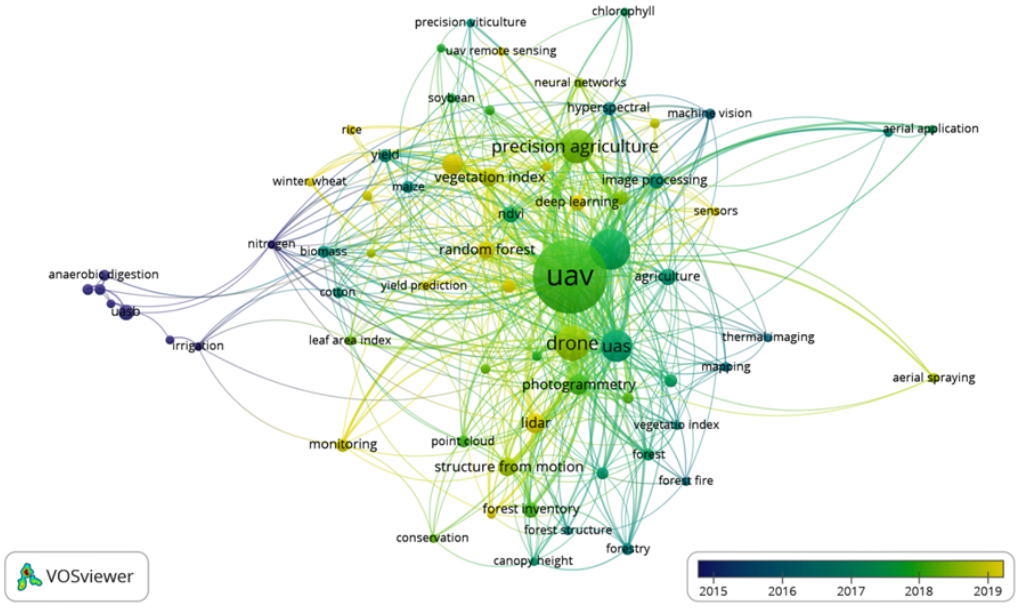

Figure 6 - Keyword co-occurrence network in the studied period (2000-2020).

author with the highest number of documents, and second in the list of citations, was classified in the same grouping as Zarco-Tejada. In addition, both of them presented a higher degree of importance until 2016, as indicated by the color grid of the overlay visualization system (Figure 7). In turn, Torres-Sanchez and Penã J. were represented with the highest rate of citations in the period between 2017 and 2018 and Zhang C. between 2018 and 2019.

Analysis of citations between countries

The top-3 countries regarding the number of citations in this study were the USA, Spain, and China. Spain showed a higher number of citations

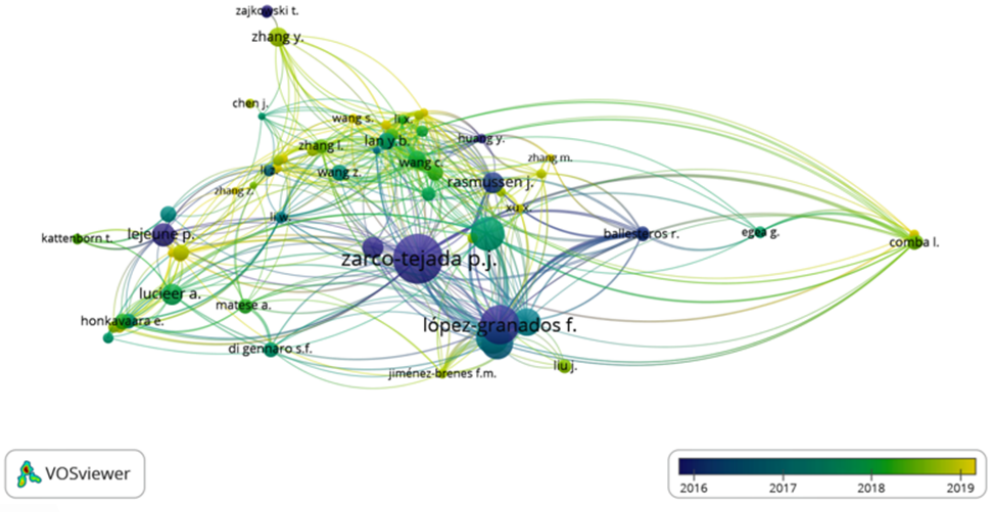

Figure 7 - Citation network among authors with at least 5 articles and 50 citations throughout the studied period (2000-2020).

up to 2016, while the USA was the first on the list between 2016 and 2017. Conversely, China showed a greater impact after 2018, as can be seen in the map by the overlay visualization system (Figure 8). Although, China ranked second in the world's production of articles in the area, the research conducted in this country may be more recent, which would explain the lower number of citations. Australia, Germany, France, United Kingdom (UK) and Canada were more representative between 2017 and 2018. Portugal, Indonesia, Russia and Ireland had the greatest impact after 2019.

The UK presented a well-diversified network of connections in terms of citations. The proximity on the map with countries, such as France, Belgium, Germany, and the USA implies a strong work citation relationship between these countries. In general, Canada, USA, Sweden, Australia, UK, Spain, Brazil, New Zealand, Germany, France, Japan, China, Italy, and Russia presented a good relation between article citations.

Analysis of citations between journals

The top-5 journals in terms of citations were Remote Sensing of the Environment, Computers and Electronics in Agriculture, Bioresource Technology, Precision Agriculture, and Forests. In figure 9, the larger the dimension of the sphere that represents the journal, the higher was the number of citations received by the journal throughout the studied period.

The proximity of the spheres on the map indicated a strong relationship of citations between the Computers and Electronics in Agriculture and Precision Agriculture, indicating a convergence of studies published in these journals. The occurrence of five groups was also evidenced, which showed strong connections with other journals indicated under the same color. This interaction that occurs between citations of certain journals can be considered important information both to facilitate the search for similar topics by different journals, as well as to point out which journals tend to have a better acceptance of articles according to their scope. In addition, there are journals, that published a very high number of special issues often with very similar topics.

DISCUSSION

In this study, a bibliometric and scientometric analysis was used to review the existing literature dataset at the Scopus platform on the use of UAVs in agriculture, forestry, and livestock. Through these analyses, it was possible to build indicators to assess the scientific production of researchers, areas of knowledge, and countries (SILVA et al., 2011).

Although, UAVs emerged several decades ago, their use in agricultural and forestry has been studied more frequently in the last 5 years. The increase in the number of published articles is an important reference of research progress and may

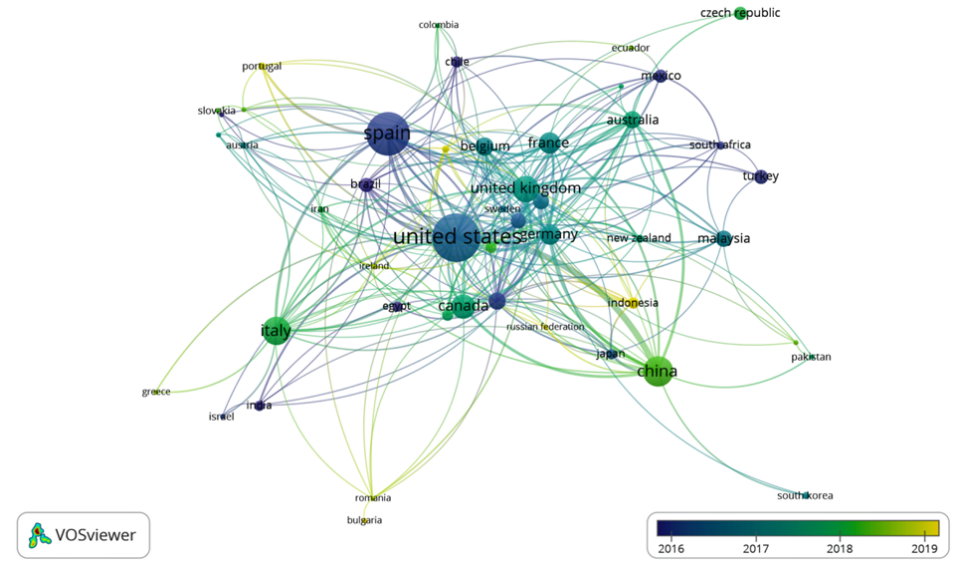

Figure 8 - Citation network across countries throughout the studied period (2000-2020).

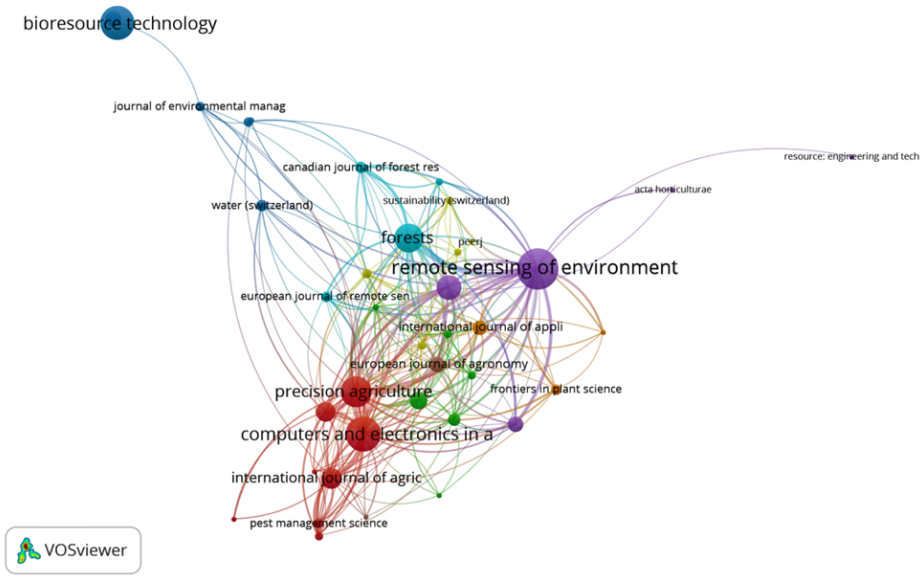

Figure 9 - Citation network between journals throughout the studied period (2000-2020).

reflect the focus of research attention over a certain period of time (WANG et al., 2019). Since 2018, the number of articles published on the topic each year has been higher than all records between 2000 and 2010.

One of the reasons for this increase in publications may be associated with the diversity of functionalities of these types of equipment and the benefits brought by them. For example, UAVs with optical, thermal, and radar sensors, associated with geo-referencing systems, enabled the monitoring and mapping of anomalies that, if observed from the ground or by traditional techniques, would not be as obvious or even could be noted (NEBIKER & LACK, 2016).

Currently, several countries have been conducting studies with UAVs. However, the two major contributors to world research are the USA and China. RAPARELLI & BAJOCCO (2019), who carried out a bibliometric analysis on the use of UAVs in agricultural and forestry studies, also mentioned the USA and China as the top countries with the most contributions in this area.

Even though China has ranked as the top-2 in the number of publications, the number of citations from studies produced there has not followed the same trend. It is known that several of these studies produced are published in Mandarin and this may have hindered the use of these articles by researchers who are not fluent in that language. In addition, for the present study, only publications in English were considered. Conversely, since 2013, Chinese researchers are becoming more favorable to publication in journals that use the English language for broader exposure of their research (WANG et al., 2019).

The analysis of the keywords is one way to understand the temporal evolution of studies within the same scope. Keywords are the core of scientific articles as it is a highly summarized form of content, *i.e.*, keywords with high frequency suggested the topic of common interest among researchers in a particular field of research (LI et al., 2013; ZHAO et al., 2015). Terms such as navigation, aircraft, and localization that were common in the early 2000s indicated the most common applications, in which UAVs were used at that time. On the other hand, the diversity of keywords found between 2015 and 2020 described more precisely which applications the UAVs have been used. Another important information obtained through the scientometric analysis was that the keywords found are more common in agriculture and forestry than in livestock studies, indicating that the latter area still tends to evolve.

Regarding the citation network among authors, it is clear that some researchers had their articles most mentioned, even with a smaller number of records in the literature. This fact may be related to the specificity or complexity and originality of the study or even the impact factor of the journal, in which the study was published. Similarly, the organization with the highest number of citations gains importance, even without belonging to the top-

2 countries with the highest number of publications. The Superior Council for Scientific Investigations in Spain achieved high citation rates in scientific productions. This condition suggests that the research carried out at this center has high international prestige and becomes a reference in the use of UAVs in agriculture, livestock and forestry.

Finally, the scientific mapping technique used in this study showed that the use of UAVs in agriculture, forestry, and livestock is an emerging field of research worldwide with a multidisciplinary point of view as corroborated by RAPARELLI & BAJOCCO (2019).

CONCLUSION

The use of UAVs has been an important tool in several fields. In the agriculture and forestry sector, the use of UAVs has undergone changes over the years and the evolution of technology itself has driven these changes. To better understand these applications, a bibliometric and scientometric study was carried out based on articles filtered from Scopus platform, which resulted in 1564 records in the area from 2000 to 2020.

Two countries, the USA and China, accounted for more than 38% of the publications up to the period analyzed, reinforcing the need for greater dissemination of this technology. More than 50% of the countries in the world presented some scientific record with the use of UAVs in the agriculture, livestock and forestry sector. Even though they are not the most expressive agents in the production of scientific studies, some authors and some institutions have gained recognition in this field, being constantly cited for their contributions in this field.

Through the VOS viewer software, it was possible to understand the evolution of the applicability of UAVs by analyzing the keywords used in publications over the years. The constant increase in scientific production supported two ideas: i) the use of UAVs is still undergoing transformations and is directly related to the advancement of technology included in these equipments; and ii) studies in the area are not yet sufficient to explore all the applicability of UAVs in the agriculture, livestock and forestry sectors.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analysis, or interpretation of the data; in the writing of the manuscript, and in the decision to publish the results.

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AUTHORS' CONTRIBUTIONS

Conceptualization: H.M.F.M., M.R.F.J., E.L.V. and R.N.M.; methodology: H.M.F.M., M.R.F.J., and E.L.V.; software: H.M.F.M.; writing – original draft preparation: H.M.F.M.; writing – review and editing: H.M.F.M., M.R.F.J., E.L.V. and R.N.M.

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