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THE IMPORTANCE OF USING GIS IN INCREASING THE EFFICIENCY OF AGRICULTURAL FARMS - A BIBLIOMETRIC APPROACH

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Abstract

Modern agriculture faces many challenges, including the need to feed a growing global population, cope with climate change, soil degradation and biodiversity loss. GIS technology provides solutions to these problems through its ability to collect, analyze and visualize complex geospatial data. This technology allows farmers and researchers to make informed decisions based on accurate and up-to-date data, which is why they play an essential role in modern agriculture, enabling the development of innovative solutions to global challenges, contributing to more efficient, sustainable and productive agriculture higher. In this work, we proposed that, starting from the existing data in the WOS and Scopus international databases, to analyze the existing research with the aim of identifying the major trends in GIS-related research, which includes both the evaluation of the volume and the temporal distribution of publications and the identification of popular and emerging research topics, by analyzing citations and impact factors, we can evaluate the influence and relevance of research in the field of GIS. Additionally, through a comprehensive review of existing literature and the application of bibliometric analysis, this research has identified gaps and highlighted future research needs within the GIS domain, this being essential for the direction of future research directions and for the development of new projects and initiatives that to address these gaps as well. Following the restrictions applied, it started from a number of 81,566 articles, the refinement establishing a number of 903 articles that address issues related to the use of GIS in agricultural farms, of which only 19 are those that analyze their role in assessing the efficiency of our activities, the results demonstrate that GIS is a dynamic and expanding research field with broad applicability and significant impact. Our analysis of collaboration networks indicates that the United States, China, the United Kingdom, and Australia lead in international publications and collaborations, essential for the innovative application of GIS. Our research shows a significant increase in GIS-related publications, reflecting growing academic interest and the integration of fields such as environmental monitoring, natural resource management, and precision agriculture.

Key words: *GIS, advanced technologies, agriculture, profitability, bibliometric analysis*

INTRODUCTION

The world is under the impact of rapid progress in terms of the development and use of data and information sources, an important role played by globalization that has facilitated access to technology and data, improved international collaboration and contributed to addressing complex problems with humanity is facing. Additionally, it has enhanced the availability of international geospatial data sources, such as satellite images and remote sensing data, that are essential for the application of GIS. At the same time, it also facilitated the distribution of technologies advanced by these systems worldwide, allowing access to resources not only in developed countries, but also among developing countries. Thus, GIS has become indispensable for resource management, urban and rural planning, disaster response, and environmental monitoring, thereby supporting sustainable development and effective global resource management.

Geographic Information Systems (GIS) also play a crucial role in agriculture by offering advanced tools and techniques for managing and analyzing spatial and non-spatial data, allowing both accurate mapping of agricultural land and continuous monitoring of the state of crops. By using satellite imagery and remote

sensing data, farmers can get up-to-date information on plant health, soil moisture levels and weather conditions. The fact that these systems contribute to the analysis of soil properties and the distribution of natural resources, is a help for farmers, as a result of the fact that they ensure the optimization of the use of fertilizers and pesticides, contributing to a more efficient use of resources, but also to a reducing the costs and impact of agriculture on the environment [1, 16]. The creation of detailed land maps, including information about plots, irrigation and infrastructure, have a direct impact on crop rotation planning, irrigation management and yield monitoring, but also on the analysis of the spatial variability of agricultural factors (soil, humidity, nutrients, etc.)) [6, 7, 29]. By identifying areas with different performance, farmers can apply precision farming practices, adjusting inputs according to the specific needs of each area. By evaluating crop productivity, informed decisions can be made to manage risks associated with climate change and extreme weather events, such as droughts and floods, while also measuring their environmental impact (soil erosion, water pollution), practices can be developed sustainable and conservation measures can be implemented [12].

Completed by other categories of agricultural-specific software, daily, weekly and seasonal activities in agriculture can be followed, optimizing the use of resources, but also reducing downtime in the activity carried out, expenses and income can be followed, making it easier thus making economic decisions. Another advantage is related to monitoring the performance of equipment in real time, which contributes to maintenance planning and the prevention of breakdowns, to ensuring the traceability of products from the farm to the consumer, to improving transparency and compliance with food safety regulations, to the efficient management of supply chain, optimizing delivery routes and reducing post-harvest losses, etc [17, 18, 19, 28].

In this context, the aim of the paper is to identify the major trends in GIS-related research, which includes both the evaluation of the volume and the temporal distribution of publications and also the emerging research topics, by analyzing citations and impact factors, which reflect the influence and relevance of research in the field of GIS.

MATERIALS AND METHODS

Bibliometric analysis is a powerful tool for evaluating and understanding the dynamics of scientific research, which uses statistical and mathematical techniques to analyze scientific publications. Bibliometric methodologies and indicators allow the identification of trends in the field, the evaluation of their impact and the facilitation of collaborations.

The study we carried out followed the analysis of the relevance of GIS in the most relevant specialized research, identified starting from the scientific articles in the Web of Science and Scopus databases, these being the most popular platforms for scientific research and which are used internationally. Another advantage of them is the fact that they allow finding articles whose appearance begins in the early years of the 19th century.

Through the research carried out, we followed the outline of a critical image regarding the existing studies, out of the desire to identify their future challenges and opportunities.

The objectives of the research were the following:

1: Identification of the main research groups in the field of GIS application in the management of agricultural farms

2: Identification of the distribution of scientific production regarding the application of GIS in agriculture

3: Identifying the gaps related to the use of GIS in the management of agricultural farms

The two databases were consulted on April 30, 2024. The first keyword used in the bibliometric analysis was "agricultural farm" and a number of 81,566 articles and works were identified in the Scopus database. The search was also carried out in the WOS database. Further, the research was refined based on the keyword, "GIS system", a number of 903 researches being identified. The refinement was achieved by using the term "Efficiency", obtaining a number of 19 articles that were analyzed with the help of the VOSviewer software. In the conceptual maps

made, the size of the network nodes indicates the relevance within the research, and the thickness of the curves and the distance between the nodes provide information about the connection established between the elements under analysis.

RESULTS AND DISCUSSIONS

The topic of the GIS approach applied in agriculture began to be researched starting with 1999, through a number of 3 articles which then grew exponentially.

The largest number of articles on this topic were published in 2021, their number being 222, with 6,429 citations.

In 2023, 195 articles were published, cited 7,378 times, and in 2024, until May 25, 64 articles appeared in the WOS database, cited 2,435 times (Figure 1).

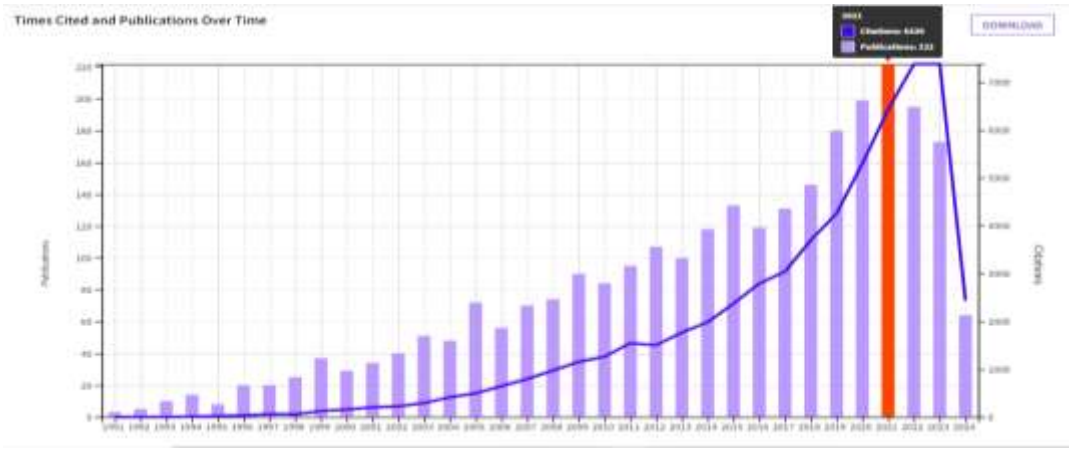

Fig. 1. Evolution of the number of articles published in the field of GIS systems in agriculture
Source: WOS [30].

By examining the correlation between co-authorship and authors, we can gain insights into the dynamics of scientific collaboration, the structure of academic networks, and the influence of these collaborations on scientific output. Thus, we can establish the situations in which 2 or more authors collaborate for the publication of a research.

In the present case, putting as a restriction the publication of a minimum number of 5 articles per author, the result was that out of the 3,149 authors, 20 met this criterion, Wang Y. standing out, with 11 published articles and 13 total links strength.

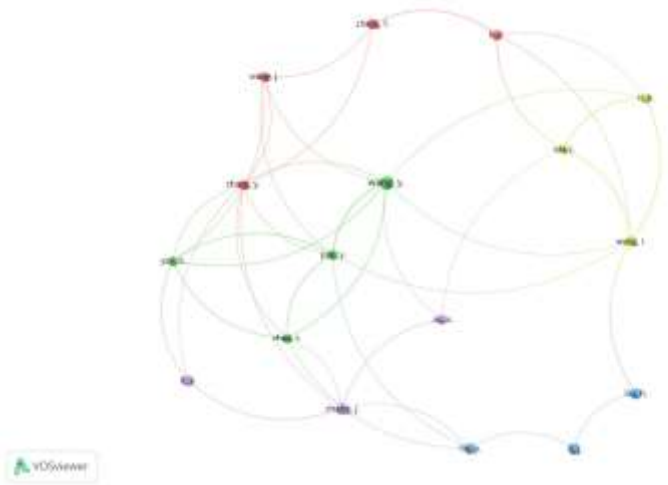

Fig. 2. Distribution of scientific research according to co-authors
Source: VOSviewer own processing.

The authors were grouped into 5 clusters between which 40 links were established. Although Zhang Y. published a number of 9 articles, the total link strength was 7, which is why Pan Y. and Wang I. occupy the 2nd and 3rd places (although they only have 6 articles each, but having total link strength of 12, respectively 11) (Fig. 2).

Co-occurrence measures the frequency with which 2 or more keywords appear together in the same publication. In the current analysis of the 7,608 keywords appearing in the selected articles, and having the condition that a keyword has a minimum number of 5 occurrences, we found that this was fulfilled by 674 words. The most used keyword was GIS, with 512 occurrences and a total link strength of 6,878, followed by "geographic information system" with 372 occurrences and a total link strength of 5,631 and agriculture with 232 occurrences and a total bond strength of 3.723. The 674 items were grouped into 5 clusters, with a total power of 95,129 links established between the 47,071 links (Fig. 3).

Therefore, "GIS" is a central term in recent research, with a large number of occurrences and a dense network of connections. The clustering of the articles indicates the various research subfields, demonstrating the complexity and interconnectivity of studies related to the use of GIS both in agriculture and in other fields, some related. This bibliometric analysis thus gives us a comprehensive perspective on the importance and influence that GIS have in academic research.

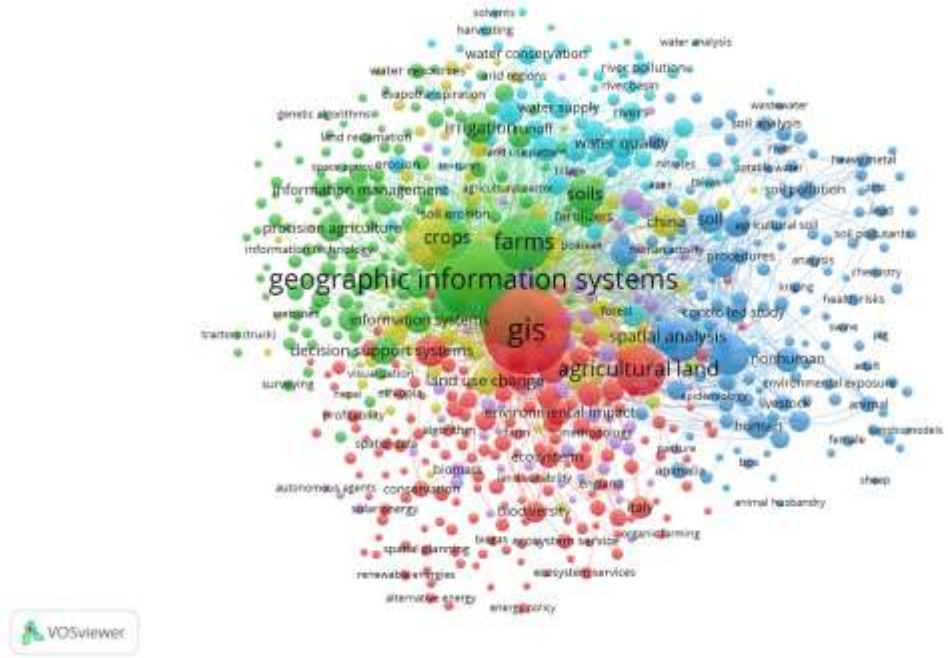

Fig. 3. Distribution of scientific research according to keywords
Source: VOSviewer own processing.

Analyzing the relationship between the key terms selected by the authors and the frequency with which they appear together in the same publication, and setting as a restriction the appearance of a minimum number of 5 keywords, it resulted that out of the 2,858 keywords, only 80 met this criterion. The first 3 positions were "GIS", "remote sensing" and "agriculture", with 247 occurrences, 80 and 38 respectively. The total intensity of links was 284, 119 and 64, respectively. These were grouped in 11 clusters between which 363 links were established and which had a total intensity of 715.

Thus, the keywords, having a significant number of occurrences and links, underline the interconnectedness and importance of the the efficiency of the activ covered. Clustering and dense network of links highlight complexity

and collaboration in GIS and remote sensing research in agriculture (Fig. 4).

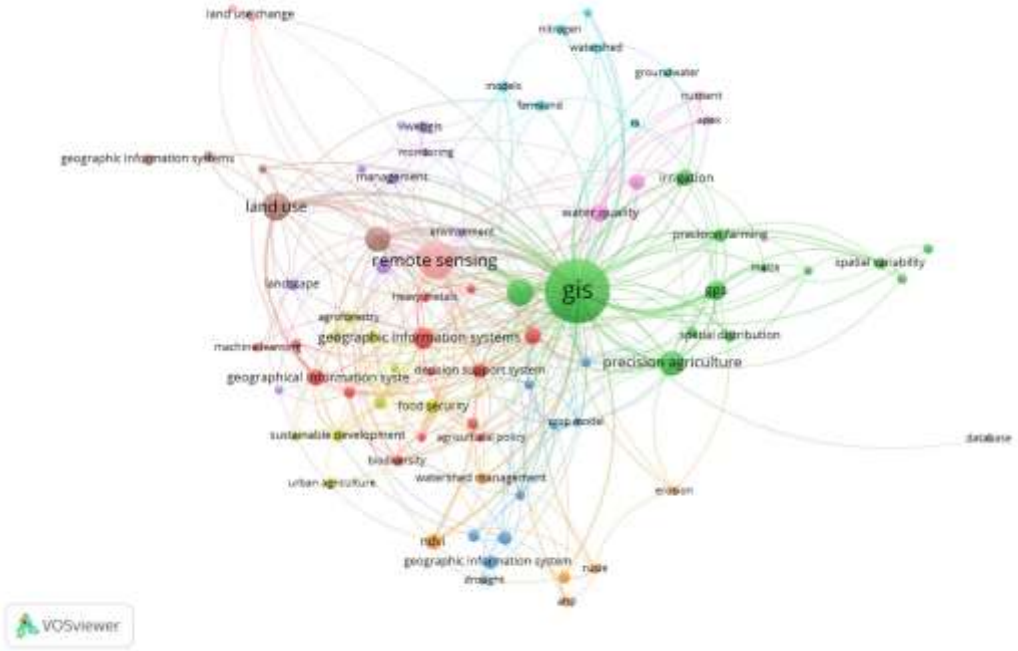

Fig. 4. Distribution of scientific research according to keywords and authors
Source: VOSviewer own processing.

The link between citations and the article's country of origin allowed us to determine the influence and impact of scientific research at the national level, facilitating the understanding of global contributions, as well as that of international collaboration networks. Thus, the leading countries were highlighted, as well as the trends of transnational collaboration. Starting from a minimum number of 25 citations per country, out of the 104 countries, only 48 fulfilled this condition. The highest number of citations belongs to the USA, with a number of 169 articles, cited 3,968 times, which occupies the leading position in addressing the subject related to the application of GIS in agriculture. It is followed by China, with 161 published articles and 2,665 citations and Italy with 70 articles and 1,340 citations.

In order to identify the similarity between scientific documents that have a number of common references, we made the correlation between bibliographic coupling and sources, and using a minimum number of 10 citations, as well as a number of 5 articles per source, it resulted that out of the 492 articles, only 30 met these criteria.

These were grouped into 8 clusters, establishing a number of 59 links between them.

Thus, the keywords, having a significant number of occurrences and links, underline the interconnectedness and importance of the topics covered.

The clustering and dense network of linkages highlight the complexity and collaboration in GIS and remote sensing research in agriculture. We thus account for the existence of a narrow but well-connected network of articles that share common references.

Clustering reflects distinct research subfields and collaborations between them (Fig. 5).

In order to determine the research gaps, given and with the aim of developing new research directions in the field of using GIS to increase the profitability of the activity carried out within agricultural farms, we analyzed the most relevant works in this field. After applying the filters, 19 articles resulted. The main findings of the analysis undertaken are presented in Table 1.

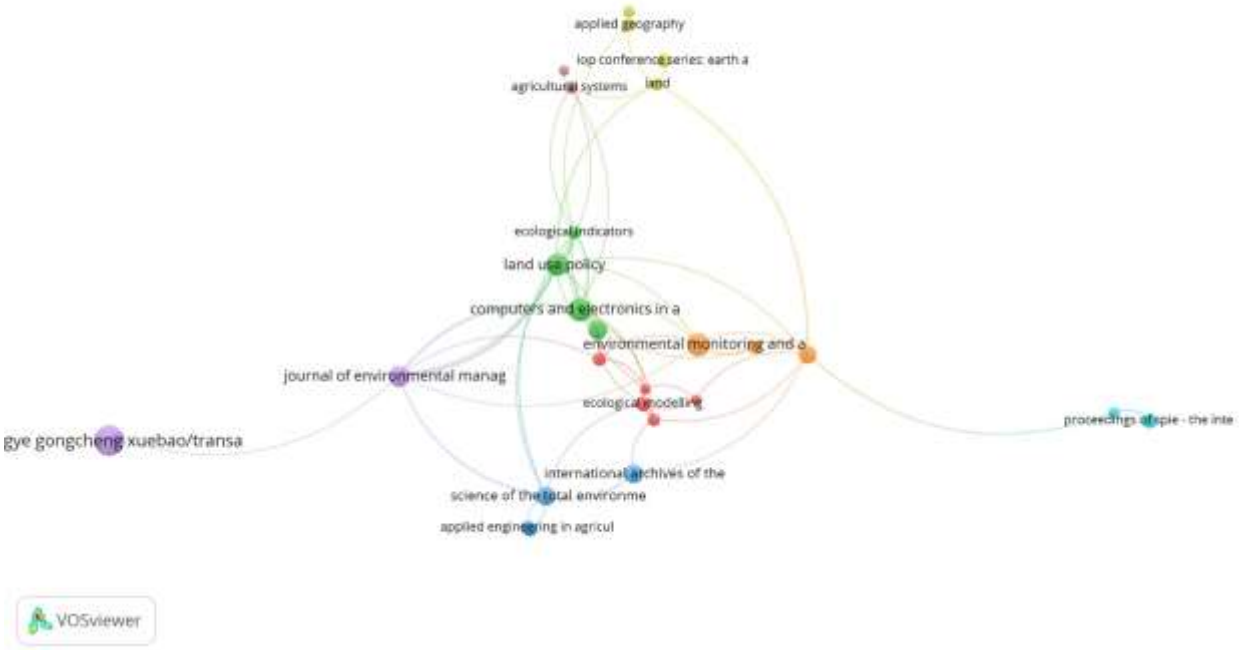

Fig. 5. Distribution of scientific research according to bibliographic coupling and sources
Source: VOSviewer own processing

Table 1. Summary of research results in the field of "GIS" use in agricultural farms and their economic efficiency

Author(s)	Year of publication	Title	Number of citations	Main findings
Shahhoseini, H., Ramroudi, M., Kazemi, H	2023	Emergy analysis for sustainability assessment of potato agroecosystems (case study: Golestan province, Iran)	2	The analysis of GIS system usage in the research involved collecting and interpreting data related to the spatial distribution of urgency indices, which were calculated based on the provided inputs and outputs of the agrosystems specific to the cultivation of autumn potatoes in the Golestan region, in Iran. Based on the case study carried out, the authors were able to make recommendations regarding the application of sustainable technologies, aiming both at increasing the economic efficiency of farms and protecting the environment [24]
Sbahi, M.K., Ziboon, A.R.T., Hassoon, K.I.	2021	Evaluation of the Efficiency of Circular Wheat Crop Farms Using GIS and Remote sensing Techniques	2	In the research, GIS systems were used to estimate the areas cultivated with wheat in the region of Ain al-Tamur, Iran, a hard-to-reach area, which makes this possible due to the use of technology. At the same time, an evaluation of the quality of the productions was carried out, using different remote sensing indicators [23]
Longo, M., Dal Ferro, N., Lazzaro, B., Morari, F.	2021	Trade-offs among ecosystem services advance the case for improved spatial targeting of agri-	12	Starting from the importance of ecological agriculture for protecting the environment, the research performs a comparative analysis of some BAU and AEM scenarios, for the Veneto region,

		environmental measures		Italy. In this sense, high-resolution spatial data related to pedo-climatic conditions, agricultural land management and environmental data were integrated with the aim of identifying recommendations on how to efficiently exploit ecosystems [15]
Ghosh, S., Mistri, B.	2020	Drainage induced waterlogging problem and its impact on farming system: a study in Gosaba Island, Sundarban, India	23	The research examines the causes of waterlogging and their implications for coastal agriculture in the Sundarban area. The remote sensing and GIS techniques allowed the authors to identify the spatio-temporal changes of the drainage network resulting from the overlay analysis performed, related to the multi-temporal vector layers [11]
Babajanov, A.R., Abdivaitov, K.A.	2020	Organizational support for automation of land management projecting in irrigated areas of Uzbekistan	-	The research analyzes the ways of creating automated agricultural land management systems. Additionally, the paper explores the integration of artificial intelligence systems to evaluate the economic efficiency of agricultural projects, which includes the use of GIS technologies. The conclusions reached by the authors highlight the reduction of costs and the elimination of some deficiencies, which recommends, from an economic point of view, their use in the design of agricultural land management [2]
Gaudėšius, R.	2016	Drawing up maps of infertile soil plots using geographic information systems	1	Recognizing the significance of practicing efficient agriculture, there is a need for detailed maps that illustrate soil fertility and land use, the paper creates such a map using geographic information systems, but proceeding to the preparation of maps of agricultural holdings. Cercatrea also highlights the advantages and disadvantages of the software used, being rather a case study addressed to specialists [10]
Dong, Z., Zhou, Q., Wang, D., Chen, Z.	2015	Optimization of spatial sampling schemes and elements for estimating farmland area	-	Starting from the importance that the information related to the mapping of agricultural lands has in the development of food policies and in economic planning in China, but also on the application of an efficient management of crops, the authors of the work highlight the importance of the use of geographic systems in achieving this objective, insisting on the application correctness of information collection methodologies. Thus, the paper presents a case study regarding the application of sampling, proving that sampling errors can have consequences on the economic efficiency of agricultural holdings, thus providing a theoretical basis regarding the improvement of the spatial survey

				methodology with a role in estimating the cultivated agricultural area [8]
Karunaratne, A.S., Walker, S., Azam-Ali, S.N.	2015	Assessing the productivity and resource-use efficiency of underutilised crops: Towards an integrative system	3	The research presents the advantages of using a platform for managing the situation regarding the different categories of underutilized crops, offering support regarding different decisions that can be taken, starting from a quantitative basis that is the basis for determining their economic efficiency and productivity. The application also allows the integration of different indicators that measure the effects of climate change and their impact on agricultural activity, as a result of both the use of GIS and major models for crops from around the world. CropBASE case studies provide yield and water use productivity predictions for various crops in Saharan and Sub-Saharan Africa [13]
Calvert, K., Mabee, W.	2015	More solar farms or more bioenergy crops? Mapping and assessing potential land-use conflicts among renewable energy technologies in eastern Ontario, Canada	102	The research is an integrated approach to land use and energy planning, carrying out a regional analysis. Based on an elaborated methodology, we try to locate the land that can support the production of bioenergy and solar photovoltaic production, but also to identify the ways in which the land must be used so that its potential can be reached on the market. At the same time, the advantages and disadvantages associated with choosing one of the systems over the other are estimated and evaluated. GIS systems, as well as overlay techniques, are used to locate mutual lands, highlighting once again their important role in current conditions [5]
Sharma, S., Manhas, S.S., Sharma, R.M., Lohan, S.K.	2014	Potential of variable rate application technology in India	8	The paper analyzes the possibility of more efficient use of different categories of inputs related to agricultural production with the aim of improving the efficiency of their application, on the one hand for economic reasons, and on the other hand as a measure to reduce environmental pollution. Based on the study, it turns out that what can contribute to changing the way farmers manage both culture technologies and the results obtained are global positioning systems (GPS), as well as geographic information systems (GIS) [25]
Kokkinidis, I., Hodges, S.C.	2013	Calculating ecosystem services provided by agricultural land using GIS and remote sensing methods	-	The work, based on the study of agricultural farms in an area of Virginia, is a complex one, having several objectives. One of these is the estimation of productions for 15 crops starting from the existing information

				in the databases and which were collected with the help of GIS. Another objective was to determine the conservation value of cultivated land. Those parcels whose destination can be changed, with the aim of obtaining biofuel, without this affecting production requirements, were also identified. Different economic indicators were also calculated, and the effects of carbon flows on the obtained productions were also measured. [14]
Farrow, A., Risinamhodzi, K., Zingore, S., Delve, R.J.	2011	Spatially targeting the distribution of agricultural input stockists in Malawi	10	The research aims to analyze 3 key aspects related to the distribution of agricultural inputs in the Malawi region of Africa. The obtained results demonstrate the fact that a spatial analysis can contribute to the expansion of the distribution network of inputs, and based on the evaluation of the degree of coverage with outlets, the optimal locations for them could be obtained. The study used both spatial analysis and different location-allocation models [9]
Nahry, A.H.E., Ali, R.R., Baroudy, A.A.E.	2011	An approach for precision farming under pivot irrigation system using remote sensing and GIS techniques	58	The paper analyzed the efficiency of the use of agricultural land and water based on a case study carried out in the Ismailia area of Egypt. At the same time, the economic and ecological profitability of practicing precision agriculture in an experimental field that uses pivot irrigation for the corn crop was monitored, proving its effectiveness [21]
Shinners, T.J., Digman, M.F., Panuska, J.C.	2010	Overlap loss of manually and automatically guided mowers	-	The work analyzes the losses due to overlaps in the case of the use of agricultural machinery. Based on a controlled experiment and a case study carried out at the farm level and using several categories of machinery, it has been demonstrated that the use of automatic guidance systems contributes to the reduction of overlap losses [27]
Shi, Z.-H., Chen, L.-D., Hao, J.-P., Wang, T.-W., Cai, C.-F.	2009	The effects of land use change on environmental quality in the red soil hilly region, China: A case study in Xianning County	26	The research analyzes the effects of climate change in the Xianning region of China, due to the change in land use. The data that formed the basis of the case study were collected with the help of remote sensing technologies, geographic information systems and from the analysis of the main spatial components, proving their importance in the collection and interpretation of information [26]
Barton, D.N., Faith, D.P., Rusch, G.M., Paniagua, L., Castro, M.	2009	Environmental service payments: Evaluating biodiversity conservation trade-offs and cost-efficiency in	40	The work demonstrates the role of GIS in the collection and analysis of data related to environmental protection costs in Costa Rica. In the present case, their use together with a software application (TARGET), analyzes the

		the Osa Conservation Area, Costa Rica		PES allocation criteria, demonstrating the fact that they were much more effective in the period 2002-2003 compared to those in the period 1999-2001 [3]
Bongiovanni, R.G., Robledo, C.W., Lambert, D.M.	2007	Economics of site-specific nitrogen management for protein content in wheat	19	The research analyzed the established relationships between crop yield, protein and nitrogen quantities, using both regression analysis to monitor yields. They were converted with the help of geographic information systems (GIS), which proves the necessity and importance of their use [4]
Murray, R.I., Yule, I.J.	2007	Developing variable rate application technology: Economic impact for farm owners and topdressing operators	12	The paper analyzes the costs and economic efficiency of using modern aerial systems in the agricultural activity of farmers, demonstrating that these costs are not prohibitive and that they are efficient from an economic point of view [20]
Padgitt, S., Petrzelka, P., Wintersteen, W., Imerman, E.	2001	Integrated crop management: The other precision agriculture	3	The research analyzes the opportunity of applying precision agriculture and their dependence on the use of GPS and GIS. The study emphasizes that implementing integrated crop management can enhance both the economic efficiency of farms and the effectiveness of environmental protection measures. This conclusion is supported by a case study conducted in Iowa [22].

Source: Own precessing.

The analysis of the 19 articles on the role of GIS in enhancing the competitiveness of agricultural farms highlights a strong focus on evaluating the impact of these tools to improve the efficiency of precision agriculture. This demonstrates a significant concern with understanding how GIS applications can optimize agricultural practices and increase farm productivity, monitoring and analyzing processes in real time, planning activities and making decisions starting from computerized information, but also the impact they have on reducing costs, increasing profitability, sustainability and resource conservation. However, we found that there are certain limits related to the availability of data, the complexity of the technology used, its cost, the adaptability of these solutions, but also the social impact of their use, which makes a holistic approach necessary to eliminate these challenges and to maximize the positive impact of GIS on the agricultural sector.

It is noteworthy that most studies are based on case studies or other secondary research methodologies, which lead to solutions that can be implemented in practice.

CONCLUSIONS

The analysis of scientific articles confirms that GIS is an important tool in increasing the competitiveness of agricultural farms, as a result of improving resource management, optimizing production processes and facilitating computerized decisions, which make GIS contribute to increasing the efficiency and sustainability of modern agriculture.

We would like to note the growing interest of researchers regarding the subject of GIS and its role for agricultural activity.

Analyzing the relationship between GIS and the increase in the profitability of agricultural holdings will allow not only the optimization of resources, the improvement of management

decisions, the monitoring and anticipation of some problems, but also the adaptation to climate changes and the promotion of sustainability, current aspects that concern both the scientific and the business environment. Providing useful and necessary tools to farmers will contribute to finding solutions related to how they will be able to face modern challenges, but also to maximize the efficiency and profitability of agricultural activity.

- the contributions brought by this research are represented by the fact that:
- the paper also contributes to the scientific understanding of how GIS can enhance the performance of agricultural farms, which results from the systematization of existing knowledge
- the work allows the measurement of gaps in the field of research, requiring the completion of new studies
- the current research has identified gaps, highlighting opportunities for expanding scientific exploration in the analyzed field.

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