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Mapping the ICT in Agricultural Research: A Bibliometric Analysis

Adriana Novotná

Faculty of Economics, Technical University of Košice, Slovak Republic

Abstract

In recent years, the information and communication technologies (ICT) with the agricultural sector has garnered significant attention due to its potential to transform and optimize agricultural practices. This study provides a comprehensive picture of the previous and current state of ICT in agricultural research, thereby shedding light on the existing knowledge landscape and key research themes. The study presents a mapping research approach that explores the conceptual structure of ICT in agriculture research using co-occurrence analysis drawing upon the Web of Science database with the results of 8,654 documents that have been published from 1989 to 2023. From a total of 2,930 keywords and the five most frequent keywords have been identified as: "performance", "growth", "expression", "impact", and "identification". The findings from this study contribute to the broader understanding of the ICT-agriculture research landscape and provide valuable insights for researchers, practitioners, and policymakers in this evolving field.

Keywords

Agricultural research, ICT, co-occurrence analysis, scientific map, VOSviewer.

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Introduction

In the 1970s, researchers started showing interest in the potential of computer technology in agriculture. These early stages were associated with the development of software applications for managing agricultural data (Brockington, 1979), such as yield management (Joyce and Griffin, 1978), crop planning (Bauer and Cipra, 1973), and farm management improvement (Connor and Vincent, 1970). Since that time, there has been a significant transformation in the utilization of technologies, marked by notable advancements and changes. Information and Communication Technologies (ICT) have become a vibrant topic in various sectors, revolutionizing the way how to collect, analyse, and disseminate information. One such sector where the application of ICT holds significant potential is agriculture. The intersection of ICT and agricultural research opens new avenues for improving productivity sustainability, and decision-making in the agricultural industry.

In 2011, World bank (2011) published a document about ICT in agriculture that presents various case studies from where ICT has been utilized to support the agricultural sector primarily focused on developing countries. The publication examining the utilization of ICT in agriculture and its potential benefits for smallholder farmers and highlights the challenges and limitations in implementing ICT in agriculture. The significance of ICT has been also examined and affirmed through various publications, such as Lin, et al. (2017) arguing that an ICT e-agriculture with a blockchain infrastructure is the next step in the evolution of ICT e-agriculture. Gangopadhyay et al. (2019) conduct their study in India, where agriculture is the main source of livelihood for most of the population and the sector is acutely susceptible to the impacts of climate change. They claim that ICT-based climate information and agro-advisory services can help to manage agricultural inputs (water, seed, fertilizer, and energy) to get maximum benefit of good climatic conditions. Chowhan and Ghosh (2020) analyse features of ICT in agriculture in Bangladesh and claiming that future of farming will be more information based, computerized, software oriented and wireless. A study by Li et al. (2023) carries out a review of smart agriculture and production practices in Japanese large-scale rice farming contributing that smart technology enables data collection and mining for efficient agricultural production. In these publications, authors endeavoured to evaluate the practical utilization of ICT in selected domains, but to explore the application of ICT in agriculture, researchers can focus also on examining practical applications and utilization of ICT technologies through bibliometric analyses of publications. For example, Ayim et al. (2020) explore ICT innovations in the agriculture sector of Africa and their results show that the primary adopted ICT technologies are text and voice-based services targeting mobile phones aimed at improving access to accurate and timely agriculture information. Onyancha and Onyango (2020) analyse dominant occurrence of keywords related to agricultural domains, which represent the primary livelihoods of numerous impoverished families in sub-Saharan Africa, implies deliberate efforts to strategically employ ICTs in these areas to optimize agricultural production and foster regional development. Stefanis et al. (2022) provide the visualization mapping of the research agenda through a bibliometric analysis of 453 articles in the field of ICT and climate change that affects the productivity of agriculture in the period from 1999 to 2021. The authors claim that acquiring knowledge about the specific associations between ICTs and agricultural practices or specific tasks would significantly enhance the effectiveness and efficiency of ICT application. Recently, there is also an increasing number of examples of studying bibliometric publications in the given field, e.g., Bertoglio et al. (2021), Ribeiro et al. (2021), Punjani et al. (2023).

This study reveals a growing interest in analysing the role of ICT in agriculture, as evidenced by the increasing number of relevant documents published over the years. Based on the above-mentioned bibliometric studies we provide co-occurrence analysis method to map the field of the ICT in agriculture research between 1989 and 2023, which aims to assess significant keywords within the topic. Despite the extensive body of academic literature about ICT in agriculture in recent decades, the research landscape remains fragmented and lacks consensus. There is a need to illuminate the key factors of this significant research area over broader period. Motivated by these gaps, the present study undertakes an examination of the conceptual structure of ICT in agriculture research as an interdisciplinary field that draws upon diverse theories and knowledge from various disciplines. With the aim of expanding the existing knowledge base, this study seeks to provide insights into the current paradigms of ICT and agriculture and identify future research directions. To achieve these objectives, the following three research questions (RQ1-RQ3) will be addressed in this paper:

- RQ1: What are the most important topics in ICT and agriculture research?
- RQ2: How have the publication dynamics in the topic of ICT in agriculture research changed between 1989 and 2023?
- RQ3: What are the future directions of ICT in agriculture research?

First question seeks to identify the most significant topics in ICT and agriculture research, providing insights into the key areas of focus within this domain. Second question explores the publication dynamics over the period from 1989 to 2023, providing insights into the trends and developments within the ICT in agriculture research landscape. Lastly, the study aims to outline the future directions of ICT in agriculture research, offering valuable insights into the potential areas of growth and exploration in this field. By addressing these research questions, this study contributes to a comprehensive understanding of the previous, current state and future potential of ICT in agriculture research. To accomplish these research objectives, an extensive dataset comprising 8,654 documents sourced from the Web of Science (WOS) database is employed. The utilization of this comprehensive dataset allows for a comprehensive analysis of keywords within the field of ICT in agriculture.

Materials and methods

This study undertook a systematic review of academic research on the ICT and the agricultural sector spanning the period from 1989 to 2023. Despite prior academic attention to the topic, the study sought to assess of past and the current state of knowledge in the field and capture its developments. By examining studies published up until July of 2023, it aimed to provide insights into the most recent advancements and ensure our evaluation reflects the current understanding in the field. The study utilized the Clarivate Analytics WOS database to obtain data. The search scope focused on papers consisting of the keywords "ICT agriculture", which, after trying various versions such as "ICT agricultural" or "ICT in agriculture," yielded the highest number of results. This research string served as a focused query to retrieve relevant documents specifically related to the examined topic. A comprehensive search compiled on July 12, 2023, yielded a total of 8,654 documents relevant to the research topic. Of these, 6,905 were articles and 109 early access articles, 1,159 were proceeding papers, 560 were review articles, 102 were book chapters and the rest consists of meeting abstracts (36), editorial materials (30), data papers (12), letters (12), corrections (6), and one biographical-item and retracted publication. To map the conceptual structure of the topic, this study employed co-occurrence networks analysis using the VOSviewer software, building upon prior research by Luckyardi et al. (2022) who provide bibliometric analysis of climate smart agriculture research or Kushartadi et al. (2023) with their analysis of two decades of smart farming. This established method was selected to gain insights into the interrelationships and patterns within the ICT and agriculture research domain in general. As authors typically tend to focus solely on specific areas within agriculture, the utilization of VOSviewer in such a comprehensive manner, as presented in this study, has not been previously demonstrated.

The inception of VOSviewer can be traced back to its initial publication by Van Eck and Waltman (2010) but since that time subsequent advancements and expansions have rendered the content of the paper partially outdated, so we decided to follow the current manual by Van Eck and Waltman (2023). By visualizing and analysing the co-occurrence networks between items, researchers can identify patterns, relationships, and dependencies that might not be apparent through other methods. According to Van Eck and Waltman (2023), in co-occurrence network analysis of keywords, the co-occurrence relationships can be used to identify important keywords or topics that co-occur frequently in a corpus, enabling the discovery of thematic patterns or topic clusters. This analysis can aid in identifying hidden associations, exploring collaborative opportunities, improving recommendation systems, and gaining deeper insights into the structure and dynamics of the analysed data. The insights gained from co-occurrence network analysis can provide valuable knowledge for decision-making, knowledge discovery, and understanding complex systems. Due to the complexity of this issue and analysed keywords, special techniques such as thesaurus methodology or other advanced keyword analysis methods, we opted for a more generalized analysis approach that allowed us to explore broad trends efficiently. While this approach provided valuable insights, it should be noted that specific keyword analysis techniques were not employed, does represent a limitation in terms of potential depth and specificity in our analysis.

VOSviewer software offers three distinct visualizations for data analysis. There is network visualization, the overlay visualization, and the density visualization. In the network visualization, items are visually represented by their labels and are typically depicted as circles. The size of both the label and the circle associated with an item corresponds to its weight. A higher weight results in a larger label and circle for the item. The colour assigned to an item corresponds to the cluster it belongs to. The second one, the overlay visualization shares similarities with the network visualization, with the primary difference lying in the colour scheme assigned to the items. If items are associated with scores, their colour is determined by the score value assigned to each item. By default, the colour scale ranges from purple (indicating the lowest score) to yellow (representing the highest score). In the density visualization, items are represented by their labels, like the network visualization and overlay visualization. Each point in the item density visualization is assigned a colour that indicates the density of items in particular area. The colour of a point reflects the density of neighbouring items. Points with a higher number of items in their vicinity and higher weights of the neighbouring items tend to have colours closer to yellow (Van Eck and Waltman, 2023).

Vosviewer utilizes a similarity measure called association strength, which has been referenced as the proximity index (for example, Peters and Van Raan, 1993 or Rip and Courtial, 1984) or the probabilistic affinity index (for example, Zitt et al. 2000). The association strength, employed to determine the similarity between two items *i* and *j*, is computed as per the following formula:

$$s_{ij} = \frac{c_{ij}}{w_i w_j} \quad (1)$$

Where c_{ij} represents the count of co-occurrences of items *i* and *j*, while w_i and w_j represent either the total occurrences of items *i* and *j* or the total co-occurrences of these items.

The VOS mapping technique aims to minimize a weighted sum of squared Euclidean distances between pairs of items. The weighting factor increases as the similarity between two items increases, indicating a greater influence on the overall distance. To prevent trivial mappings where all items are in the same position, a constraint is enforced to maintain an average distance of 1 between pairs of items. Mathematically, the objective function to be minimized can be expressed as follows:

$$V(x_1, \dots, x_n) = \sum_{i<j} s_{ij} ||x_i - x_j||^2 \quad (2)$$

The vector $V(x_1, \dots, x_n)$ represents the coordinates of item i in a two-dimensional map, and ||•|| denotes the Euclidean norm. The objective function is minimized under the following constraint:

$$\frac{2}{n(n-1)} \sum_{i<j} \left| |x_i - x_j| \right| = 1 \quad (3)$$

The numerical solution to the constrained optimization problem, minimizing (2) subject to (3), is achieved through a two-step process. Initially, the constrained optimization problem is transformed into an unconstrained optimization problem. Subsequently, a majorization algorithm, a variant of the SMACOF algorithm used in multidimensional scaling literature (for example, Borg and Groenen, 2005), is employed to solve the unconstrained problem. To enhance the likelihood of obtaining a globally optimal solution, the majorization algorithm is executed multiple times, each time with a distinct randomly generated initial solution.

In the last step, VOSviewer applies three key transformations to the solution: translation, rotation, and reflection. Firstly, the solution is centred at the origin through translation. Secondly, a rotation is performed to maximize the variance on the horizontal dimension using principal component analysis. Lastly, the solution may be reflected in the vertical or horizontal axis based on the median values. According to Van Eck and Waltman (2010), these transformations collectively guarantee the production of consistent and reliable results in VOSviewer analyses.

Results and discussion

Firstly, with the aim to bring a valuable starting point to understand the academic landscape and the dissemination of research in the analysed area, Table 1 provides an overview of top 10 journals by the number of documents in the analysis. The list is organized based on the frequency of publications in each journal, offering valuable insights into the leading scholarly outlets that are significant contributors to the discourse in the field of ICT and agriculture. By presenting this comprehensive overview, it aims to highlight the prominent journals that have been published a substantial number of documents relevant during the period between 1989 and July 2023 with information of the H-index and Impact factor up to the latest available data.

The "Scientific Reports" was the top journal in terms of the number of articles with 137 documents. The number of documents 112 represented "International Journal of Molecular Science". For the others, the number of documents was below 100, for example "PLoS ONE" with the number of 95 and last mentioned, "Applied Sciences Basel", with the number of documents 57. The place of publication of these journals is in Switzerland and Germany and the United

Journal	Country	Publisher	H-index (2022)	Impact Factor (2022)
Scientific Reports	United Kingdom	Nature Publishing Group	282	4.44
International Journal of Molecular Science	Switzerland	Multidisciplinary Digital Publishing Institute	230	5.57
PLoS ONE	United States	Public Library of Science	404	3.7
Sustainability	Switzerland	Multidisciplinary Digital Publishing Institute	136	3.9
Computers and Electronics in Agriculture	Netherlands	Elsevier	149	6.757
Journal of High Energy Physics	Germany	Springer Verlag	247	5.4
Advances in Intelligent Systems and Computing	Germany	Springer Science and Business Media Deutschland	58	0.63
Food Chemistry	United Kingdom	Elsevier	302	8.8
Frontiers in Plant Science	Switzerland	Frontiers Media	187	6.627
Applied Sciences Basel	Switzerland	Multidisciplinary Digital Publishing Institute	101	2.838

Source: Prepared by author

Table 1: Overview of the top ten journals that represent ICT and agriculture research (1989 – July 2023).

Kingdom also have two representatives.

Table 2 provides an overview based on affiliations to specific organizations that can help readers to identify organizations active in ICT and agriculture research for potential collaborations and knowledge exchange.

Name	Country	Number of documents
Seoul National University	South Korea	1,231
Chonnam National University	South Korea	535
Chinese Academy of Science	China	503
Kyungpool National Universi-ty	South Korea	476
Korea University	South Korea	467
National Taiwan University	Taiwan	402
Sungkyunkwan University	South Korea	369
Kangwon National Universtiy	South Korea	305
Jeonbuk National University	South Korea	299
University of California	United States	287

Source: Prepared by author

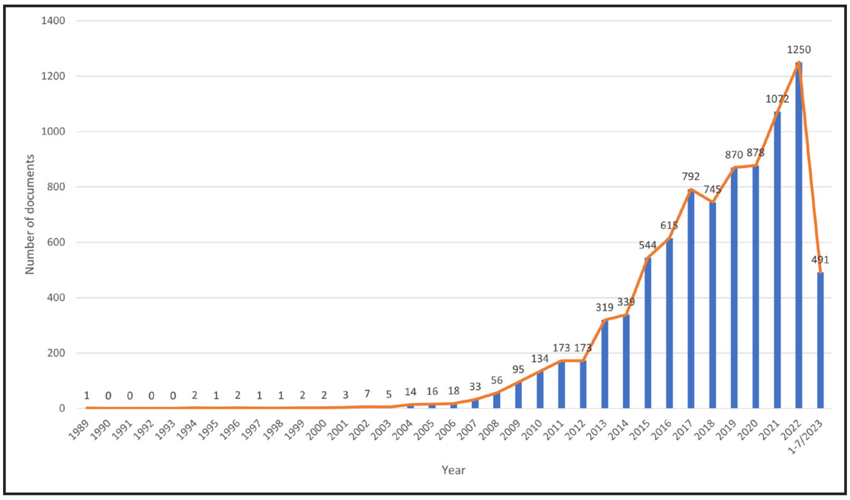
Table 2: Overview of the top ten affiliations that represent ICT and agriculture research (1989 – July 2023).

The results indicate that most organizations involved in ICT and agriculture research are universities in South Korea. This could suggest that South Korean universities are actively engaged in this research area and may be leading contributors to the advancement of innovations in the field. Their dominant presence may also indicate a strong emphasis on research and development initiatives related to ICT applications in agriculture, potentially driven by the country's agricultural landscape and the recognition of the significance of ICT in enhancing agricultural practices and productivity.

The final step preceding the actual analysis using VOSviewer was the examination of the trend in publication growth over the observed period. This trend is illustrated in Figure 1 and conducted a systematic analysis of the growth pattern of publications related to ICT and agriculture research throughout the specified time period.

The overall trend of published documents started in 1989 with one article, and over time, this number gradually increased. The count of publications in the double digits began in 2004, while three-digit figures emerged from 2010 onwards. The most significant period occurred, particularly after 2021, when more than a thousand publications were published. The highest number of studies was reported in 2022, with 1,250 documents. As of July 12, 2023, there have been 491 publications. However, given the upward trend in the number of publications, it is expected that this count will surpass the previous years, as indicated by the increasing trend presented in Figure 1.

In the following section, the study focuses on the analysis of keywords within the analysed dataset. We decided to remove the keywords "ICT" and "agriculture" from the analysis as they were primarily used to create an overview of the dataset. Including these terms in the subsequent analysis could potentially bias the results and misrepresent the actual focus of research in the field. By dividing the study into distinct timeframes, it is possible to examine how the prevalence and significance of keywords evolved during different phases of research. To capture the changes that occurred during the analysed period, we set a threshold for keyword frequency into four periods (from 1989 to 2009, from 2010 to 2020, from 2021 to 2023



Source: Prepared by author

Figure 1: Publication trend.

and all periods). Except for the first period, where only 14 keywords met the specified thresholds, Table 3 shows the top 25 frequent keywords in these time periods.

First analysed period in Table 3, from 1989 to 2009, represent the early years of research in the field, where ICT and agriculture was a relatively new topic, and the number of publications was low. Keywords with highest frequency number include "Information", "Management", "Impact", and "Internet", which reflect the growing importance recognition of the potential benefits of integrating ICT into agriculture. "Information" appears predominantly due to its representation as an abbreviation for ICT. Upon closer examination, we examined that the term "Management" can be associated with concepts such as "quality of management" (e.g., Schiefer, 1999) or "knowledge management" (e.g., Bianca, 2005 or Zschocke et al., 2007). Other keywords such as "Plants", "Gene", and "Cloning" suggest a focus on agricultural biotechnology and genetic research indicates interest in improving crop yields, enhancing plant traits, or developing genetically modified organisms to address challenges in agriculture and were predominantly observed from 2000 onwards (e.g., Macek et al., 2002; Entry et al., 2008; or Khan et al., 2009). Period from 2010 to 2020 could indicate a time when ICT and agriculture gained more attention, resulting in a significant increase in the number of publications. Analysing this period can provide insights into emerging technologies and keywords that emerged during this transformative decade. For instance, keywords like "Expression", "Identification", and "Growth" have substantially higher frequencies, indicating a surge in research focusing on emphasis on molecular and genetic research in agriculture. The combination of these keywords, for example, is found in study by Liu et al. (2013), Ryu et al. (2014), Zhou et al. (2016), etc. "Model" and "System" suggest

Keywords (1989-2009)	Fr.	Keywords (2010-2020)	Fr.	Keywords (2021-2023)	Fr.	Keywords (All Periods)	Fr.
Information	11	Expression	332	Expression	149	Expression	489
Management	11	Identification	225	Growth	133	Growth	333
Impact	9	Growth	196	Performance	112	Identification	316
Internet	8	Model	170	Impact	97	Model	258
Diversity	6	Gene	161	Quality	86	Protein	229
Plants	6	Protein	159	Identification	86	Gene	228
Accumulation	5	Management	122	Model	83	Performance	226
Expression	5	Information	118	Protein	70	Management	193
Gene	3	Performance	114	Temperature	69	Impact	186
Cloning	2	Activation	112	Oxidative stress	66	Information	184
Linked-immunosobent--assay	2	Oxidative stress	105	Gene	62	Oxidative stress	172
Model	2	Arabidopsis	102	Machine Learning	62	Quality	172
Simulation	2	Gene-expression	100	Management	61	System	165
System	1	Rice	99	System	61	Activation	162
		In-vitro	99	Information	59	In-vitro	157
		System	99	Deep Learning	58	Temperature	148
		Cells	94	In-vitro	56	Arabidopsis	141
		Biosynthesis	90	Behaviour	52	Water	140
		Evolution	90	Mechanisms	51	Rice	139
		Plants	88	Resistance	51	Resistance	139
		Water Resistance	87	Activation	50	Gene-expression	136
		Acid	86	Water	50	Apoptosis	130
		Metabolism	85	Optimization	49	Acid	129
		Systems	85	Design	48	Biosynthesis	126
		Apoptosis	84	Nanoparticles	46	Cells	125

Source: Prepared by author

Table 3: Top keywords in the ICT and agriculture research.

the use of computational and modelling approaches to understand agricultural systems and processes. "Activation", "Oxidative stress", "Cells", "Water Resistance", "Acid", "Metabolism", "Biosynthesis", "Evolution", "Plants", "Apoptosis", and "In-vitro" imply a focus on various biological processes and pathways relevant to agricultural organisms. Overall, the keywords suggest that during this period, there was a significant interest in molecular and genetic aspects of agriculture, along with continued attention to agricultural management and information technologies. The current period (from 2020 to July 2023), which represents period with increase in the number of documents beyond thousand, might represent as a phase of rapid expansion and innovation in the field. Comparing to previous periods, some keywords that were prominent in the earlier periods, such as "Internet", "Diversity", and "Plants", have been replaced by new keywords like "Machine Learning", "Deep Learning", and "Nanoparticles". This suggests an increasing emphasis on technological advancements and interdisciplinary approaches in ICT and agriculture research. Additionally, the higher frequency of keywords like "Expression," "Growth," and "Performance" in the current period indicates ongoing interest in genetic and biotechnological studies related to agricultural development and productivity. In this period, some of the most highly cited documents with the particular keywords are by Sultana et al (2020), Lin et al. (2020) or Li et al. (2020). Among the most frequently occurring keywords during all analysed periods, there are "Expression" "Growth" "Identification" and "Model" which indicate significant research focus in the field of ICT and agriculture aiming to investigate the roles and mechanisms of gene expression in agricultural systems, exploring the factors that influence agricultural growth, developing identification methods for specific agricultural components, and employing various models to simulate and analyse agricultural processes. Additionally, keywords like "Protein", "Gene", "Performance", and "Management" have consistently featured, demonstrating their sustained relevance and importance in the scholarly discourse over time.

In the following part, we conducted co-occurrence network analysis using VOSviewer. Due to the limited number of keywords, we decided to explore the network across all the periods. This approach allows us to gain a comprehensive understanding of the interconnections and relationships between various key terms in the field of ICT and agriculture. Figure 2 represents co-occurrence network analysis.

The most frequent keywords were divided into seven clusters with seven different colours. Keywords that were similar in content were grouped in a cluster. For example, the keywords "Information" and "Management" were in the blue cluster and the keywords "Model" and "Hadron-hadron scattering" were in the orange cluster. The size of the circles indicated keyword frequency, and the thickness of the lines indicated the strength

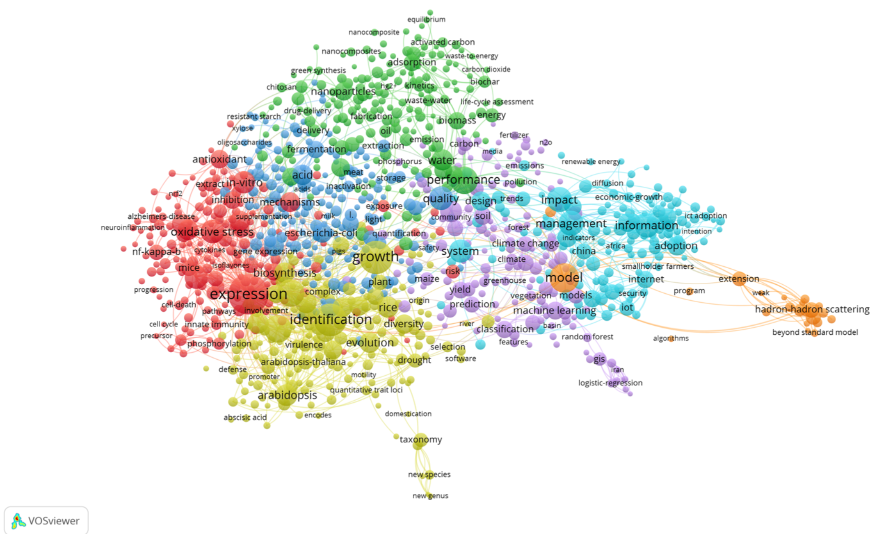


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Figure 2: Co-occurrence network analysis (1989 – July 2023).

of co-occurrence within and between clusters. As the Figure 2 shows, all the clusters were interconnected, and there were strong relationships between all seven clusters. This indicated the high interdependence of different area of ICT and agriculture research. Overall, there were 998 keywords, 7 clusters, and 39,813 links in this network, with a total link strength of 68,046. Cluster 1 (represented in red colour) emerged as the largest cluster with 183 keywords, prominently featuring the term "Expression." Within this cluster, keywords related to human entities and various diseases (e.g., oxidative stress, in-vitro) were also observed. This alignment can be attributed to the focus on investigating the expression of genes in diverse biological contexts. Cluster 2, represented in green and comprising 175 keywords, revolves around the concept of "Performance". The keywords in this cluster pertain to different forms of performance in the agricultural sector, including biomass, nanoparticles, and water, indicating a strong emphasis on assessing and enhancing agricultural productivity. Cluster 3, characterized by its dark blue colour and comprising 17 keywords, encompasses terms such as "Acid", "Fermentation", "Escherichia-coli", and "Metabolism". These keywords share a common theme of being related to biochemical processes and metabolic pathways. Cluster 4, depicted in yellow and comprising 166 keywords, prominently features terms like "Growth" "Identification" "Gene" "Diversity" "Arabidopsis" "Cloning" and "Evolution". These keywords indicate a significant research focus on the genetic aspects of plant growth and evolution. Cluster 5, represented in purple colour and encompassing 145 keywords, centres around terms such as "Machine learning", "Yield", "Dynamics", and "Climate changes". This cluster suggests a shared interest in studying the application of machine learning techniques to enhance agricultural productivity and address the challenges posed by climate changes. Cluster 6, in light blue colour and consisting of 134 keywords, is characterized by keywords like "Management", "Information", "Impact", "Adopting", and "System". This cluster highlights a strong emphasis on the management and adoption of ICT and related systems in agriculture. Cluster 7, the smallest cluster represented in orange colour with 22 keywords, includes terms like "Model", "Algorithms", "Beyond standard models" "Hadron-hadron scattering". These keywords indicate a focus on modelling and advanced algorithms, particularly in the context of complex systems and physical phenomena.

Figure 3 shows results of overlay visualization, the yellow colour denotes terms that have appeared in recent research, while purple indicate that research on a term is carried out closer to the year 2017 (Luckyardi et al., 2020 and Van Eck and Waltman, 2023). Among the darker shades, we find keywords such as "Hadron-hadron scattering", "Rice", or "Mice" that might represent more established or traditional topics in the field of ICT and agriculture. In contrast, the lightest and most recent shades, including terms like

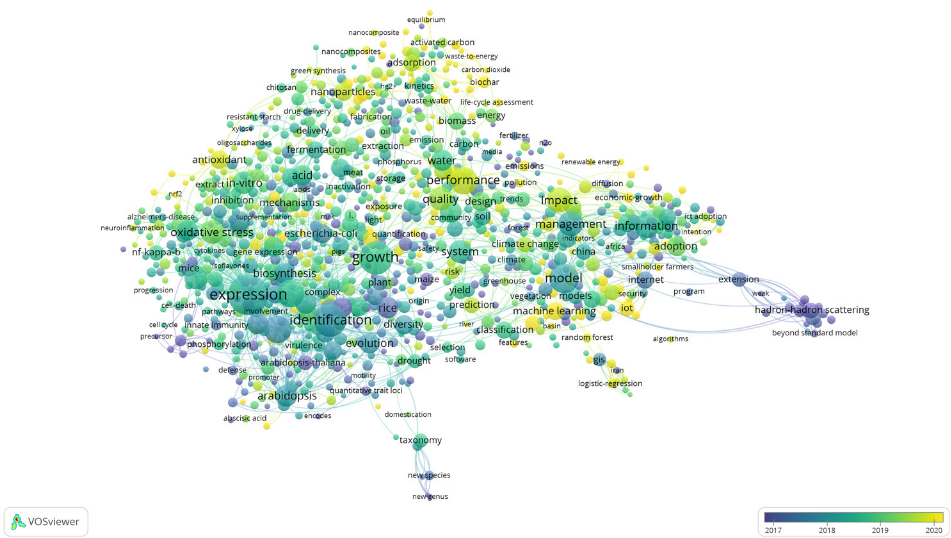

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Figure 3: Co-occurrence overlay visualization analysis (1989 – July 2023).

"Machine learning", "IoT", "Nanoparticles", and "Antioxidant", suggest that these topics are currently gaining significant attention and are likely to be the focus of recent or ongoing research in the field of ICT and agriculture.

As illustrated in Figure 4, increased density is observed within the range of Cluster 1 to Cluster 4 and their corresponding keywords. The concentration of yellow areas around Clusters 1 to 4 signifies that these clusters and their associated keywords are more prevalent and frequently occurring in the research literature. On the other hand, keywords from other clusters, such as "Management", "Innovation", "Impact", and "Model", can be also considered as frequently occurring terms.

For a more in-depth analysis, we decided to create a trend analysis of publications based on the most frequently cited keywords within each cluster. We chose to perform a trend curve analysis for the past ten years in research, using publications presented through WOS database. For this analysis, the term "ICT agriculture" is used along with the word that appeared most frequently in each cluster. As the year 2023 was still ongoing at the time of this study, we chose not to disrupt the trend analysis. Consequently, we decided to focus this examination on the previous 10-year period, encompassing the years from 2013 to 2022.The result of this investigation is shown in Figure 5.

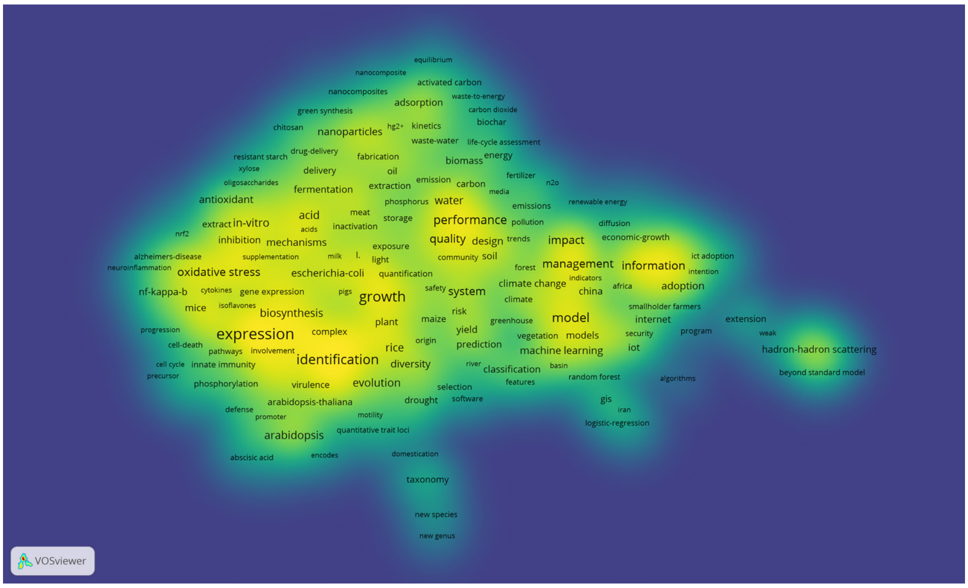

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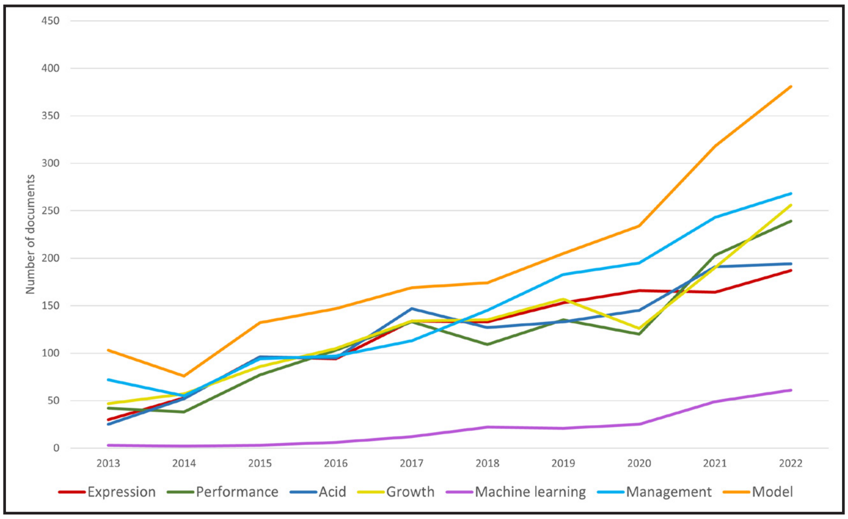
Figure 4: Co-occurrence density analysis (1989 – July 2023).



Source: prepared by author

Figure 5: Publication trend of keyword frequencies over 10 years.

According to results, the frequency of the keyword "Expression" steadily increased from 30 in 2013 to 187 in 2022, indicating a growing interest in this area of research. Similarly, "Performance" also exhibited an upward trend, reaching its peak at 239 in 2022. In contrast, keywords like "Acid" (Cluster 3) and "Management" (Cluster 6) showed relatively stable patterns over the years, suggesting a consistent focus on this topic. "Machine learning" keyword experienced a significant increase in frequency, from 3 documents in 2013 to 61 documents in 2022, reflecting the increasing importance of this technology in the domain. The keyword "Model" displayed an interesting trend over the ten-year period from 2013 to 2022. In 2013, it had a frequency of 103, indicating a significant presence in the research landscape. Over the following years, its frequency fluctuated but generally showed an upward trajectory, reaching 381 in 2022. This substantial increase suggests that the concept of "Model" gained prominence in the field of ICT and agriculture research. Such an upward trend may be indicative of a growing reliance on modelling techniques and computational approaches within this domain, reflecting a broader trend toward data-driven and simulation-based research methodologies.

Conclusion

As global challenges such as population growth, climate change, and resource constraints continue to exert pressure on the agriculture sector, harnessing the power of ICT becomes increasingly crucial. By leveraging advanced technologies, data analytics, and smart solutions, ICT can enhance agricultural productivity, optimize resource utilization, and improve supply chain efficiency. This study delved into the realm of ICT and its profound impact on agriculture with comprehensive search that has yielded a total of 8,654 documents relevant to the research topic of ICT and agriculture during the period from 1989 to July 2023, providing a substantial dataset for analysis and insights into the advancements and trends in the field over time.

The overview of top journals showcases the leading scholarly outlets that have contributed significantly to the discourse, offering a comprehensive snapshot of the most prominent publications relevant to the field over the analysed period. Notably, "Scientific Reports" emerged as the top journal with 137 articles, followed by "International Journal of Molecular Science" with 112 documents. These findings shed light on the key academic platforms that have played a pivotal role in disseminating knowledge and fostering research in this critical area. Of particular significance, South Korean universities emerged as the predominant contributors in this domain. This underscores the importance of collaboration and knowledge exchange with South Korean institutions for the advancement of research and innovation in the field. While we acknowledge that approximately half of the examined papers originate from South Korea, this regional specificity was not explicitly explored in our analysis, which can be considered a limitation of this study. Future research could delve deeper into regional nuances and their impact on research trends within the field of ICT in agriculture to provide a more comprehensive perspective.

Through the exploration of three pivotal research questions, we gained valuable insights from VOSviewer and provide comprehensive analysis of research literature spanning from 1989 to 2023 allowed us to decipher the evolving landscape of ICT in agriculture. Regarding the first research question, we identified the most important topics in ICT and agriculture research. The analysis revealed that topics such as "Expression", "Growth", "Identification", and "Model" were among the most frequently occurring keywords across all the analysed periods. Additionally, keywords like "Management", "Innovation", "Impact", and "Model" also emerged as prominent and frequently researched terms in the domain of ICT and agriculture. To understand the publication dynamics in the field, we conducted a systematic examination of research outputs between 1989 and 2023. The results showed a significant increase in the number of publications over the years, with a notable surge in research output starting mainly from 2010. This trend indicates a growing interest and focus on the integration of ICT in agriculture, reflecting the increasing importance of this field in addressing contemporary agricultural challenges. As we explore the future directions of ICT in agriculture research, our findings suggest a growing interest in emerging areas of inquiry. The analysis indicates a notable shift towards investigating cutting-edge technologies and their applicability to agricultural practices. This trend reflects the evolving nature of ICT and its increasing relevance in the agricultural sector. Given the continued importance of agriculture for livelihoods and the evolving landscape of ICT, it is reasonable to anticipate a growing body of research in this field in the coming years.

Corresponding author:
Adriana Novotná, PhD.
Department of Banking and Investments, Faculty of Economics, Technical University of Košice
Němcovej 32, 040 01 Košice, Slovak Republic
E-mail: adriana.novotna@tuke.sk

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