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Bibliometric Study of Global Research Trends on Agriculture 4.0: Publication Pattern, and Thematic Analysis

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A B S T R A C T
The present study examines the research on agriculture 4.0 from 1965 to 2022. The bibliometric approach was adopted to analyse the current research trends in Agriculture 4.0. MS Excel, R software (Biblioshiny) was utilised to analyse and visualise the data. The present study will analyse the literature's publication pattern and growth rate in Agriculture 4.0. During this period, 1869 documents were published by 7,258 authors, and 1040 sources were considered for the study. The publication pattern was analysed using different bibliometric aspects like chronological contribution of papers, year-wise growth of publication, geographical distribution of papers, authorship pattern, author productivity, etc., which provide in-depth information about the publication pattern of Agriculture 4.0. The development of Agriculture 4.0 has grown rapidly over the last decade, and despite the growing interest in it, studies are still needed to develop its theory. Agriculture 4.0 is an emerging new technology that is like a revolution in agriculture; by adopting the concept, agricultural scientists can reach a proper conclusion in the literature. It is necessary to make Agriculture 4.0 more understandable and accessible to farmers. This exciting field has led to new discoveries and expansions in agriculture. For the successful use of Agriculture 4.0, it will be necessary to make progress at all levels of crops, from specialty crops to traditional crops.

1.0 Introduction

The global population's need for food, projected to reach 9 billion by 2050, presents significant challenges to the current agricultural model. Increasing productivity, lowering costs, and conserving natural resources will be essential. Climate change, Global warming and extreme weather events are anticipated to threaten agricultural production (Pardey,P.G.,2014). Some causes, such as rural-to-urban migration and an increase in the elderly rural population daily, could impact agricultural productivity in certain regions. One promising solution to these challenges is adopting emerging technologies in agriculture (Baldos,U.L.C. and Hertel, T.W.,2014).

The application of these technologies, which work together and enhance each other in agriculture, has the transformative power to lead, known as the fourth agricultural revolution (Rose,D.C.,2021). This revolution is called Agriculture 4.0 or Farming 4.0 (Boursianis,A.D.,2022). Before discussing agriculture 4.0, we will briefly focus on agriculture 1.0 to 3.0. The combination of manpower and animal force with a simple tool like sickles, mattocks, etc., for agriculture production can called agriculture 1.0; in this phase the production is very low, whereas in the 19th century, with the help of the advancement of S&T, some changes began like the invention of steam engines, the discovery of electricity and, invention of computers have changed the face of the earth (Kukreti,T.,2023). In this phase, farmers and plenty of chemicals operated by various agricultural machinery were used, which significantly increased the efficiency and productivity of farmer work as well as some complications increases in the fields like field chemical contamination, excessive power consumption, damage of natural resources, etc., know as agriculture 2.0 (Kaur,B.,2023).

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The Application of Information and communication technology in agriculture in the 20th century, drastic changes in agriculture fields. In this respect, process automation and robotic techniques allow us to perform operations efficiently, which increases the efficiency and productivity of the agriculture process known as agriculture 3.0. Furthermore, by efficiently distributing the work among the agricultural machinery, the environmental problems induced by Agriculture 2.0 were overcome, and a reduction in the use of chemicals and an improvement in the precision of irrigation and so on were obtained (Gagliardi,G.,2022). The evolution of agriculture has moved to Agriculture 4.0, which refers to the next phase in the evolution of agricultural practices, leveraging advanced technologies and data analytics to improve productivity, efficiency, and sustainability. This concept builds on previous agricultural revolutions, incorporating digital and technological advancements to address future challenges in farming (Raj,E.F.I.,2022). However, the term agriculture 4.0 is not uniform, being confusing and related to other terms in the literature like smart farming, decision agriculture, precision agriculture, precision farming, and digital agriculture (da Silveira,F,2021). Thus, it is not an exaggeration to say that the journey of Agriculture 1.0 to 4.0 is based on the application of Industry 1.0 to 4.0.

Agriculture 4.0 is the adaptation of new technologies like the Internet of Things (IoT), big data, cloud computing, advanced robotics, and artificial intelligence into agricultural production chains. The goal of adopting these technologies is to boost productivity, enhance efficiency, and minimise the environmental impact of agriculture, along with other benefits (Lee,J.,2015).

2.0 Literature review

A literature review synthesises existing research on a specific topic, highlighting key findings, methodologies, and gaps in the literature. It provides a comprehensive overview of what is known and what remains to be explored in the field. Raj, Meghan et al. (2021) examine the role of the Internet of Things in adopting and promoting Agriculture 4.0 and reveals that the application of advanced technology like IOT, Unmanned Aerial Vehicles (UAV), Internet of Underground Things (IoT), Data Analytics, Deep Learning Techniques, and Machine Learning methods in agriculture science, what are the application and how it's helpful to achieve the increasing food demand in respect of populations.Ali, Bushara and al. (2023) examine the reshaping of Future Farming: From Industry 4.0 Toward Agriculture 4.0. discussed the issue and challenges of food security during unpredicted environmental changes and population growth. To face these challenges, the agriculture industry should adopt new strategies, incorporating IoT, AI, and other digital technologies, promising to transform agriculture into a highly efficient, sustainable, and autonomous industry. These technologies enable data collection, analysis, and decision-making without human intervention, potentially revolutionising an inefficient sector. MARINIČ, P.(2023) Discusses the role of vocational education and training in the Czech Republic and observes that transformative shifts in industrial production methods are referred to as industrial revolutions. I found that we are currently in the phase known as Industry 5.0. Similarly, advancements in agriculture are categorised in this manner, with the latest phase termed Agriculture 4.0. Mühl, Diego Durante and Oliveira, Letícia de (2022) examine the bibliometric and thematic approach of agriculture 4.0. PRISMA protocol is used for data collection, and VosViewer and Bibliometrix software are used for result generation. The results reveal two main research fronts, one focused on agriculture 4.0 development and another on the impacts of agriculture 4.0, which may be positive or negative. The research identified 21 trend topics, categorised into five axes; the first theme is Motor themes, a well-developed and important field's structure covering two directional subjects: - (a) Crops, remote sensing, and precision agriculture. (b) Geographic information systems, data processing, and land use are well-established subjects. The second themes are niche themes, representing very specialised and peripheral themes covering wireless sensor networks, data acquisition, and intelligent systems themes. Emerging or declining Themes covers (a) Artificial intelligence, monitoring, and costs. (b) Soils, fruits, and irrigation subjects. Basic themes are important but have not been developed, covering agriculture, digital agriculture, and agricultural robot subjects. High centrality and density themes cover Agricultural development, food supply, and climate change.Albiero, D.(2020) discussed the technological term agriculture 4.0 and explained various technological aspects like e Internet of Things, big data, artificial intelligence, cloud computing,

etc.Pogorelskaia, I. and Várallyai, L. (2020) focused on the role of education in agriculture 4.0. They examine how digital education makes it easy to pursue new knowledge and its skills and help to increase

agriculture production. ICT tools unlock new possibilities for on-the-job and individual workplace learning by leveraging innovative methods and educational models, such as personal learning clouds and personalised learning environments. These advancements address a key challenge and reduce existing skill gaps.Muhyaddin, S.(2023) examines the application of Industry 4.0 technologies in Iraq's agricultural sector, highlighting significant challenges such as political turmoil, infrastructure deficits, and lack of skilled labour. The study finds that Iraq faces a long journey before it can shift from oil to agriculture.Arıcıoğlu, M. A. (2020) discussed how the struggle started in the Western world to control agricultural production, especially in Germany, through Industry 4.0, which aims to digitise production for improved speed, efficiency, and flexibility. This industrial transformation shifted in agriculture 4.0 by leveraging smart farming practices and IoT technologies to enhance productivity, sustainability, and resource efficiency. This study also examined the impact of Agriculture 4.0 on traditional formatting problems and benefited globally. Beluhova-Uzunova, R. (2022) discussed the concepts, technologies, trends, issues and challenges in agriculture 4.0. Bernhardt, H et al. (2021) discussed the "challenges of agriculture through industry 4.0". The study examines the applicability of Industry 4.0 structures to agriculture and finds that Industry 4.0 approaches are beneficial for adaptation of agriculture's unique structure. Both sectors require further organisational and technical networking advancements. Singh, G. Sahu, R. (2019) discussed the bibliometric analysis of agriculture 4.0. The data harvested from the Scopus database during 2011-2019. A total of 456 articles are downloaded, and VosViewer software is used for data visualisation. Agriculture and Biological Science are the most influential subjects; Peter J.A. Kleinman, with total publications 165, is the most productive author; the Journal of Environmental Quality is the most productive, and the United States, with 105, is the most productive country found during the study. Sharma, N (2020) focused on applying the Industrial Revolution to the agricultural revolution and how technological development affects different sectors and aspects of agriculture in different ways. Varella, W. A.(2024) discussed the industry 4.0 technologies in agriculture, highlighting the use of IoT, automation, cloud storage, and Big Data for improved decision-making in planting and harvesting. Integrated Service Architecture proposes promoting a Circular Economy in Agriculture 4.0 to enhance environmental, economic, and social benefits while reducing food insecurity. Cordero, J. A. G. and Park, T.(2023) study on "Transforming Philippine agriculture through Agriculture 4.0". The results reveal that the agriculture, forestry, and fishing sectors contributed 8.9% to the Philippines' GDP, and continuous research and technology transfer further promoted digital transformation. Agriculture 4.0 is the future of global agriculture and the modernisation of agriculture in the Philippines. Viola, E. and Mendes, V. (2022) examine low-carbon transitions in Brazilian agribusiness through Agriculture 4.0. It assesses family farming, conservative agribusiness, and sustainable agribusiness. The findings demonstrate that sustainable agribusiness is most effective. Some key challenges, such as technical, institutional, and political-economic barriers, are addressed in the study.

Thus, the above study on Agriculture 4.0 explores the integration of IoT, AI, and UAVs to improve agricultural productivity and sustainability and emphasise digitalisation's role in addressing food security and environmental challenges. The research highlights the need for advanced technologies and education to modernise agriculture and meet global food demands. This synthesis calls for ongoing research and technological advancements to revolutionise the agricultural sector.

2.1 Objective of the study: the objective of the study is given below

- To explore the growth rate and citation pattern of research in agriculture 4.0 from 1965 to 2022.
- Explore the most productive source, authors, and country in agriculture 4.0 Literature.
- To identify the trending topics of research in agriculture 4.0.
- To analyse the thematic map of crucial words and know the recent trend of agriculture research from 1965-2022.

3.0 Methodology

The bibliometric approach was employed to analyse the current research trends in Agriculture 4.0 from 1965-2022, encompassing performance analysis, scientific mapping, and identifying influential authors, institutions, nations, organisations, and journals. Various techniques were used for validation, including keyword analysis, citation patterns, and thematic exploration (Sholapur, 2023). The Data extraction involved searching the Scopus database with the keyword "agriculture 4.0" in article titles, abstracts, and keywords, resulting in 1859 documents. The collected information, encompassing bibliographic details, citation counts, abstracts, references, author and title keywords, funding etc., were compiled into CSV files for comprehensive analysis.

MS Excel and R software (Biblioshiny) was utilised to analyse and visualise the data. Table 1.0 provides a snapshot of critical data elements, such as the annual scientific production rate and average citation. The dominance of articles (N=1,157) over conference papers (N=448) indicates that Agriculture 4.0 research is emerging globally. Multi-author collaborations are prevalent, with a substantial average citation per document (N=21.97), emphasising the impact of the research contributions. The findings underscore the significant scope for future research in Agriculture 4.0, revealing a field ripe for exploration and further development.

4.0 Results

Over the 67-year, (N=1869) agriculture 4.0 documents have been published by (N=7,258) authors, and (N=1040) sources are considered for the study. Table 1.0 indicates the annual growth rate of publications stands at (N=11.03%), indicating a significant increase in research output over the years. The documents have an average age of (N=6.74) per year, suggesting a mix of recent and older studies. Each document has been cited approximately (N=21.97) times, highlighting the impact and ongoing relevance of the research. The total number of references cited across all documents is (N=72,813), demonstrating extensive research and discourse. International collaboration is a feature of the modern research environment, with (N=19.42%) of documents having co-authors from different countries.

Table 1.0 Main Information about Dataset

Description	*Result*	*Description*	*Result*
Timespan	1965-2022	International co-authorships %	19.42
Sources (Journals, Books, etc)	1040	DOCUMENT TYPES	
Documents	1859	Article	1157
Annual Growth Rate %	11.03	Book	17
Document Average Age	6.74	Book Chapter	104
Average citations per doc	21.97	Conference Paper	448
References	72813	Conference Review	19
Keywords Plus (ID)	12041	Editorial	2
Author's Keywords (DE)	5383	Erratum	17
Authors	7258	Letter	1
Authors of single-authored docs	103	Note	3
Single-authored docs	118	Review	89
Co-Authors per Doc	4.5	Short Survey	2

4.1 Annual Scientific Growth and Citation Pattern

Fig.1.0 represents the significantly increased over the years. From sporadic single-digit publications between 1965 and the mid-1980s, which was expanded Linear from 1965 to 1995, not more than six articles (N=1.32%) annually. After that, there is a noticeable uptick starting in the late 1990s,from 1996 to 2017, the growth rate has been observed up and down frequently, with (N= 27.77%) annual growth. The aggregate (N=241.2%) annual growth rate was noted in the last five-year. The growth rate for the

last five-year is 2018, N=76(4.08%); 2019, N=158(8.49%); 2020, N=266(14.30%); 2021, N=316(16.99%) and the highest publication N=390 (20.97%) noted for the year 2022.

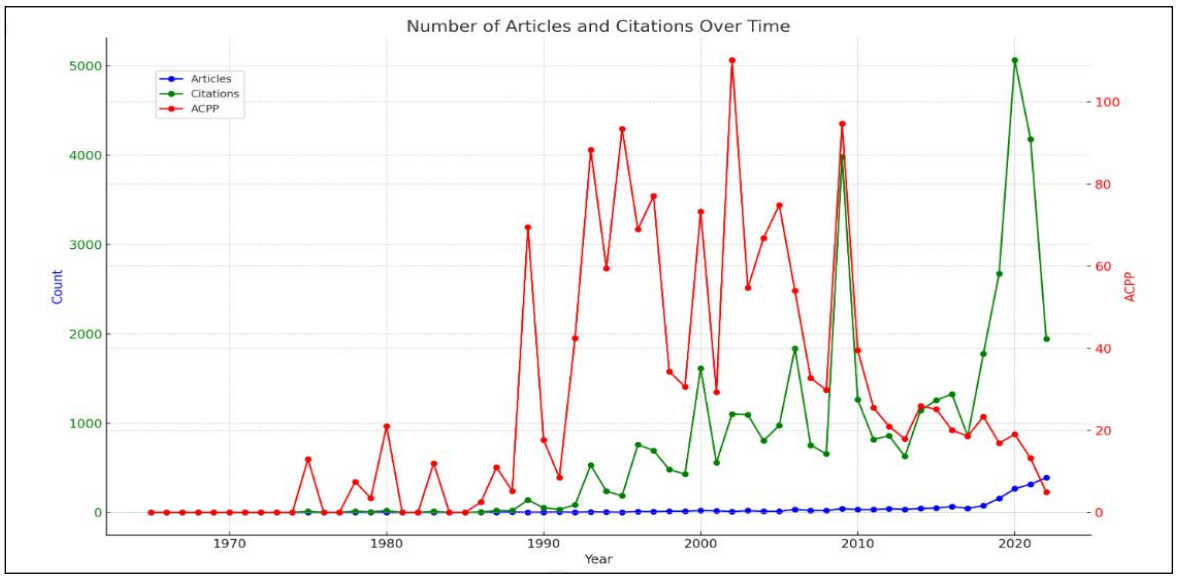


Figure 1.0 Indicate the publications growth rate and average citations per papers

Similarly, It is clearly visible in figure 1.0 that the citation pattern of literature is not linear; the pattern reflects ups and downs. The year 2009 is the most cited year with (N=3980) citation after that sudden fall visible, then upwords patterns are visible from 2011 to 2021, but a sudden fall noted in the citation pattern in 2022. The upwards rate of publications and citations suggests a widespread acceptance of research within the scientific community, with significant influence from technological advancements. There are notable citation peaks observed in 2002, 2009, and again in 2020-2022, indicating years with highly influential publications. The ACPP varies significantly across the years. Some of the highest ACPP values are observed in years with fewer publications, suggesting that a few highly cited papers can substantially boost the average.The average (N=21.97) citations per document noted during the whole study period. whenever the High values are observed in certain years with fewer publications, such as (N=110.20) in 2002 and (N=94.76) in 2009.

4.2 Most Relevance Source

The h-index is a metric that measures a researcher's impact and productivity. It is based on the relation of the number of published papers by a researcher and the citations received by those papers. A higher h-index indicates a more influential body of work. Table 2.0 demonstrates the ten most relevant sources in Agriculture 4.0. Computers and Electronics in Agriculture, are the top sources with the highest (N=11 h-index,N=15 g-index and N=0.733 m-index). Journal of Environmental Quality was the second most relevant source with an (N=11 h-index,N=12 g-index and N=0.354 m-index); the third most common source was Science of the Total Environment with (N=11 h-index, N=16 g-index and N=0.5238 m-index). On the basis of number of publications, the journal of IOP Conference Series: Earth and Environmental Science noted the highest relevant source with (N=51) publications followed by the journal AGRONOMY (N=21) and the Journal NongyeGongchengXuebao/ Transactions of the Chinese Society of Agricultural Engineering (N=19). Whenever based on citations, the journal NATURE (N=1918) is the most cited journal, followed by Journal of Environmental Quality (N=1058) and the journal of Soil and Tillage Research (N=869) citations. The sources Computer, Environment, and Agriculture are dominating sources in Agriculture 4.0.

Table 2.0 Top Ten most prolific source

Rank	*Sources (Journal, Conference, Etc.)*	*H-index*	*G-index*	*M-index*	*TC*	*NP*	*PY-start*
1	Computers and Electronics in Agriculture	11	15	0.7333	861	15	2009
2	Journal of Environmental Quality	11	12	0.3548	1058	12	1993
3	Science of the Total Environment	11	16	0.5238	556	16	2003
4	Agronomy	10	21	2.5000	606	21	2020
5	Soil and Tillage Research	10	10	0.3704	869	10	1997
6	Environmental Monitoring and Assessment	9	12	0.4737	420	12	2005
7	NongyeGongchengXuebao/Transactions of The Chinese Society of Agricultural Engineering	8	11	0.5714	153	19	2010
8	Procedia Computer Science	8	14	1.6000	222	17	2019
9	Sensors	8	13	2.6667	174	14	2021
10	Journal of Cleaner Production	7	7	0.8750	330	7	2016

Samuel C. Bradford's 1934 Bradford's Law is employed to identify the core journals within a research domain. The analysis categorises all journals into three groups, each accounting for approximately one-third of all articles. The analysis helps to highlight the concentration of productivity in core journals. The depiction of this research, conducted using R software, can be seen in Figure 2.0; a total of 1041 journals are identified in this study. First is a core zone, which has N=70 (6.72%) journals with N=616 (33.13%) articles, the second zone is N=357 (34.32%) journals with N=630 (33.88%) articles, and the third zone is N=613 (58.94%) journals with N=613 (32.97%) articles. The first five core journals on agriculture 4.0 are IOP Conference Series: Earth and Environmental Science; Agronomy; NongyeGongchengXuebao/Transactions of The Chinese Society of Agricultural Engineering; Procedia Computer Science; RevistaCienciaAgronomica.

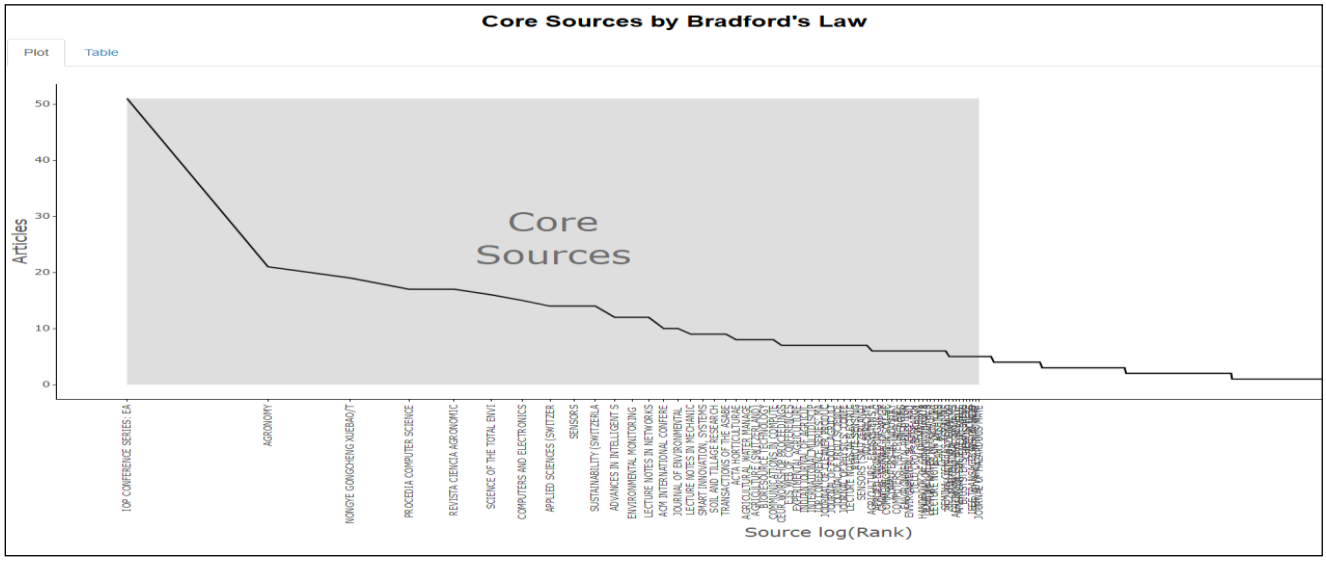


Figure 2.0 Core sources within the relevant literature

4.3 Top Productive Articles

Table 3.0 demonstrates the top ten most prolific Articles in agriculture 4.0.The article published by Wang Y. (2006) on the Removal of Methylene Blue from Aqueous Solution by Chaff in Batch Mode received the highest number of citations (N=226) published in the Journal of Hazardous Materials, is a most influential author during the study period. Li Y (2020) study published on the topic Construction of Au Nanoparticles on Choline Chloride Modified Glassy Carbon Electrode for Sensitive Detection of Nitrite, in the journal Biosensors and Bioelectronics as second highest (N=150) citation score. The title of the top ten highest cited publications indicates that carbon Electrode, Methylene, Ammonium, Nitrite, Palygorskite Nanocomposite, Runoff and Erosion of Soil, Simulated Rainfall, Future Crops, Fertilisation Rates, Nitrate Leaching, Fate of Nitrogen, Straw Return Accompany, Microbial Biosynthesis Strategies etc. Based on the Total Citation per year, the article Designing Future Crops: Challenges and Strategies for Sustainable Agriculture written by (Li J,2021) received the highest TCPY (N=24.3) published in Plant Journal. Out of ten articles, author Li H contributed the highest three articles, followed by Li Y.

Table 3.0 Top ten cited publications

Rank	*Author*	*Year*	*Title*	*Journal Name*	*DOI*	*TC*	*TCPY*
1	Wang Y	2006	Removal of Methylene Blue from Aqueous Solution by Chaff in Batch Mode	Journal of Hazardous Materials	10.1016/J.Jhazmat .2006.02.029	226	12.6
2	Li Y	2009	Construction of Au Nanoparticles on Choline Chloride Modified Glassy Carbon Electrode for Sensitive Detection of Nitrite	Biosensors and Bioelectronics	10.1016/J.Bios.20 09.04.006	150	10.0
3	Wang X	2014	Highly Efficient Adsorption of Ammonium onto Palygorskite Nanocomposite and Evaluation of Its Recovery as A Multifunctional Slow-Release Fertilizer	Chemical Engineering Journal	10.1016/J.Cej.201 4.04.097	89	8.9
4	Wang L	2017	Effects of Tillage Practices and Slope on Runoff and Erosion of Soil from The Loess Plateau, China, Subjected to Simulated Rainfall	Soil and Tillage Research	10.1016/J.Still.20 16.09.007	86	12.3
5	Li J	2021	Designing Future Crops: Challenges and Strategies for Sustainable Agriculture	Plant Journal	10.1111/Tpj.1510 7	73	24.3
6	Li H	2011	Influence of N Fertilization Rates, Rainfall, and Temperature on Nitrate Leaching from A Rainfed Winter Wheat Field in Taihu Watershed	Physics And Chemistry of The Earth	10.1016/J.Pce.201 0.03.017	72	5.5
7	Li H	2007	Modelling Transport and Fate of Nitrogen from Urea Applied to a Near-Trench Paddy Field	Environmental Pollution	10.1016/J.Envpol. 2007.02.003	67	3.9
8	Li Y	2018	Straw Return Accompany with Low Nitrogen Moderately Promoted Deep Root	Field Crops Research	10.1016/J.Fcr.201 8.02.009	64	10.7
9	Kumar A	2014	Improved Microbial Biosynthesis Strategies and Multifarious Applications of The Natural Biopolymer Epsilon-Poly-L-Lysine	Process Biochemistry	10.1016/J.Procbio .2013.12.009	56	5.6
10	Li H	2010	Identification of QTL Underlying Vitamin E Contents in Soybean Seed Among Multiple Environments	Theoretical and Applied Genetics	10.1007/s00122-010-1264-2	49	3.5

4.4 Productivity Among Scientists

Lotka's law is a tool for understanding scientific productivity patterns within a defined research field. This law posits that a substantial majority, exceeding 60%, of contributions to a particular item or field should originate from a minority of individuals. According to the results shown in table 4.0, (N=7,258) authors wrote (N=1,859) documents,out of which N=6,351(87.50%) authors have published only one

article (out of total authors). The distribution of the publications is diversified where 415(5.71%) authors with two publications, 121(1.66%) authors with three publications, 38(0.52%) authors with four publications, 30(0.41%) authors with five publications, ten authors with six publications, seven authors with seven publications, one authors with eight publications, three authors with nine publications, two authors with ten publications, two authors with thirteen publications and many single authors written more than a hundred article. So on the basis of above statistical data, it is said that the application of lotka's law is not perfectly implemented in agriculture 4.0 literature.

Table 4.0 Productivity among scientists based on Lotka's Law

Documents written	N. of Authors	Proportion of Authors
1	6351	0.909
2	415	0.059
3	121	0.017
4	38	0.005
5	30	0.004
6	10	0.001
7	7	0.001
8	1	0
9	3	0
10	2	0
11	1	0
12	1	0
13	2	0
14	1	0
15	1	0

4.5 Top ten prolific authors

Table 5.0 indicates the top ten most prolific authors based on various indexes, number of publications and number of citations in Agriculture 4.0. Li, H. is noted as the most prolific author with (h-index =8, g-index=14, m-index=0.47; publication N=14; Citation, N=289), followed by Li, Y. (h-index =8, g-index=12, m-index=0.47; publication N=12; Citation, N=399) and Wang J (h-index =7, g-index=10, m-index=0.41; publication N=13; Citation, N=103),. The citation pattern indicates that Famiglietti JS, Rodell M, and Velicogna I have the highest citation (N=1918) each, followed by Klerkx with citations (N=1067). It was found that Chinese authors dominate based on the number of publications and the quality of the publications.

Table 5.0 Top ten most prolific authors

Rank	*Author Name*	*h-index*	*g-index*	*m-index*	*TC*	*NP*	*PY-start*
1	Li H	8	14	0.470588	289	14	2007
2	Li Y	8	12	0.470588	399	12	2007
3	Wang J	7	10	0.411765	103	13	2007
4	Wang L	7	13	0.500000	220	13	2010
5	Wang X	7	13	0.636364	190	15	2013
6	Zhang Y	7	11	0.875000	170	11	2016
7	Chen Y	6	7	0.428571	256	7	2010
8	Liu X	6	7	0.400000	188	7	2009
9	Wang Y	6	10	0.333333	309	10	2006
10	Zhang J	6	10	0.352941	123	10	2007

4.6 Most Productive Affiliations/University/Organizations

Figure 3.0 demonstrates the top 10 most productive affiliations/universities/organisations. A total of (N=1,943) institutions, universities and organisations were identified for publishing literature on agriculture 4.0 research. China Agricultural University has the highest number of published articles, totalling (N=67). This indicates a significant contribution to agricultural research, likely reflecting the institution's large research output and possibly its emphasis on areas critical to China's agricultural sector.

Stuttgart's affiliation has published (N=41) articles, the second-highest number in this dataset. This could represent the university or a research institute in Stuttgart, Germany, showcasing its strong research activities. Zhejiang University is shown to have (N=39) publications, positioning it as a prominent player in agricultural research. As a major university in China, its research output underscores its role in advancing agricultural knowledge. Nanjing Agricultural University follows closely with (N=34) publications, which suggests a robust research environment focused on agriculture, possibly underlining its contribution to agricultural sciences in China. With (N=31) publications, Lanzhou University is also a significant contributor to the field. The research output from Lanzhou indicates a focus on agricultural or related scientific disciplines. The subsequent affiliation has (N=30) publications but is labelled as Not Reported, which suggests that the affiliating institution was not disclosed or is unknown for these publications. Northwest A&F University has contributed (N=29) articles, which signifies its role in agricultural research, particularly in the northwestern region of China, where agriculture is a crucial part of the economy. Gansu Agricultural University, which has (N=27) articles, like Lanzhou University, is also based in the Gansu province of China, highlighting the region's agricultural research and education investment. International Hellenic University (IHU) shows (N=25) publications, indicating its international collaboration and research impact in the agricultural sector. Lastly, the University of California, with (N=24) publications, reveals its global standing in agricultural research, given the university's broad scope of research interests and substantial funding.

The data points towards a strong representation of Chinese institutions in the top ten affiliations, illustrating the country's substantial investment and focus on agricultural research. Additionally, institutions like IHU and the University of California indicate the global nature of agricultural research endeavours.

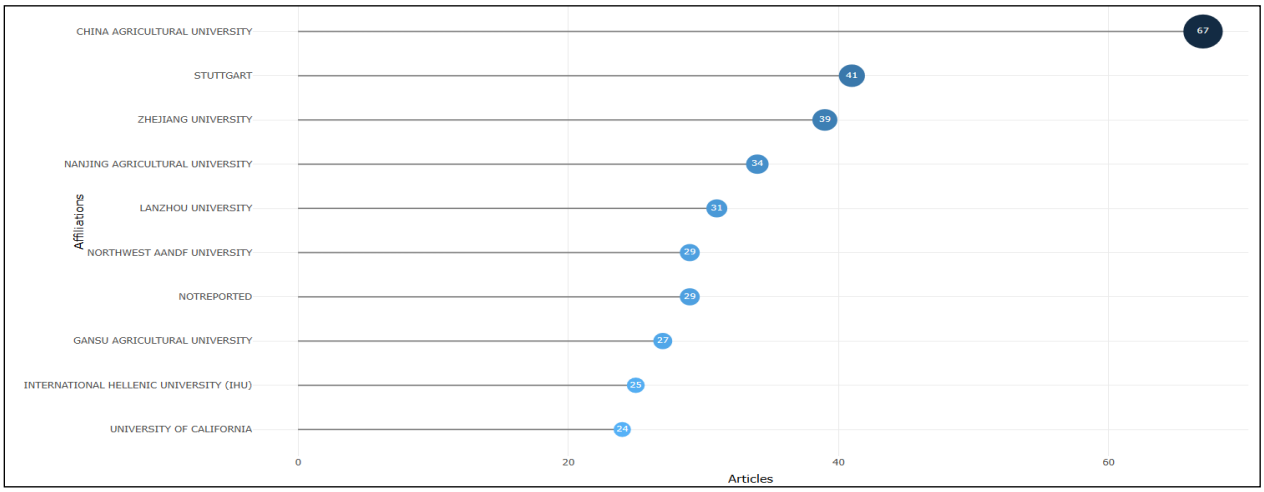


Figure 3.0 Most Productive organisation

4.7 Most Profitable Country

The table 6.0 ranks the top ten countries in the field of agricultural research based on total citations, average article citations, and scientific production.USA is at the top with the highest number of total citations (N=6,773), which indicates that the research from the USA is highly referenced in other works. The average article citations are (N=53.8), suggesting that each paper is cited frequently, indicating a high impact. The scientific production of the USA is (N=898) articles, which is substantial but not the

highest. China has the highest scientific production, with (N=1,167) articles, indicating that China is the most prolific regarding the number of research papers produced. However, its total citations are lower than the USA at (N=4,912), and the average article citations are (N=29.2), suggesting that while the volume is high, the impact per article may be less than that of the USA. India comes third in scientific production with (N=742) articles and has a total of (N=2,313) citations. The average number of article citations stands at (N=19), which is lower than in the USA and China, suggesting that the individual articles may have less impact on average. Italy has produced (N=574) articles with (N=1,484) citations and an average citation count of (N=17.9) per article, indicating a moderate impact in the field. United Kingdom has the second-highest average article citations at (N=54.5), which is very close to the USA's average, signifying a high impact per article, despite having a lower total number of articles (N=169) and total citations (N=1,363). Brazil has a scientific production of (N=600) articles with (N=1,307) citations, but the average article citations are the lowest among the top ten at (N=13.8), indicating a lower impact per article. Spain has produced (N=205) articles with (N=1,240) citations and an average of (N=40) citations per article, showing a higher impact per article than some countries with more articles. The Netherlands stands out with the highest average article citations at (N=126.4), which is remarkably high, indicating that although it has produced only (N=61) articles, the impact and quality of these articles are very significant. Turkey has (N=95) articles with a total of (N=952) citations and an average citation of (N=39.7), suggesting a solid impact per article. France closely follows with an average article citation of (N=55.3), which is among the highest, indicating a high impact per article despite having only (N=101) articles. Australia is not in the top ten but is mentioned with (N=142) articles with an average citation rate of (N=40.9) and (N=899) citations.

Table 6.0 Top 10 Most Cited and Publishing Country

Rank	*Country*	*Total Citations*	*Average Article Citations*	*Scientific Production*
1	USA	6773	53.8	898
2	CHINA	4912	29.2	1167
3	INDIA	2313	19	742
4	ITALY	1484	17.9	574
5	UNITED KINGDOM	1363	54.5	169
6	BRAZIL	1307	13.8	600
7	SPAIN	1240	40	205
8	NETHERLANDS	1138	126.4	61
9	TURKEY	952	39.7	95
10	FRANCE	940	55.3	101
11	AUSTRALIA	899	40.9	142

4.8 Evaluation of keywords and research Hotspot

Table 7.0 presents an analysis of keywords related to agriculture 4.0. It showcases their frequency and the distribution of their mentions over different time quartiles, indicating their emergence and prominence over time. Water quality (N=12 mentions) has been a consistent topic since 2008, with its median year of mention in 2012, indicating an early focus on this area, which has likely been sustained due to ongoing environmental concerns. Wheat (N=13 mentions) and Phosphorus (N=10 mentions) became prominent in the literature around 2013, suggesting a possible increased focus on crop production and soil nutrients, respectively. Yield (N=25 mentions) and productivity (N=11 mentions), with a median mention year of 2017, reflect ongoing concerns in agricultural efficiency and output, which are central to food security and economic sustainability. Soil (N=12 mentions) has been a topic of interest since 2001, with a peak in mentions around 2018, reflecting its foundational importance in

agriculture and perhaps innovations or concerns that have arisen in soil management. Climate change (N=25 mentions) shows a median mention year of 2019, which may indicate a surge in research and discussions around its impact on agriculture in recent years. Agriculture (N=84 mentions) and irrigation (N=24 mentions) have their median mention year in 2020, indicating these traditional topics remain central to the discourse, possibly with new developments or challenges. The emergence of Agriculture 4.0 (N=201 mentions) and Industry 4.0 (N=153 mentions) with a median mention year of 2021 reflects the rapid integration of advanced technologies such as IoT, AI, and automation into agricultural practices. Internet of Things (N=87 mentions), Blockchain (N=26 mentions), Digital Transformation (N=20 mentions), and automation (N=16 mentions) all have a median mention year of 2021 or 2022, showing the very recent and robust entry of these technologies into the agricultural sector. suggesting a transformative shift towards more data-driven, interconnected, and automated agricultural systems**.**

Table 7.0 Top 15 keyword occurrence (obtained by R-software data mining)

Sr. No	Key Words	freq	year_q1	year_med	year_q3
1	Water Quality	12	2008	2012	2017
2	Wheat	13	2013	2016	2021
3	Phosphorus	10	2013	2016	2021
4	Yield	25	2014	2017	2021
5	Productivity	11	2010	2017	2022
6	Soil	12	2001	2018	2020
7	Climate Change	25	2015	2019	2021
8	Agriculture	84	2018	2020	2021
9	Irrigation	24	2017	2020	2021
10	Food Security	18	2019	2020	2021
11	Agriculture 4.0	201	2020	2021	2022
12	Industry 4.0	153	2020	2021	2022
13	Internet Of Things	87	2020	2021	2022
14	Blockchain	26	2021	2022	2022
15	Digital Transformation	20	2021	2022	2022

Figure 4.0 illustrates the frequent utilisation of crucial terms in Agriculture 4.0, analysed using R software (Biblioshiny). The keywords, including “Precision agriculture,” “Agriculture 4.0,” “Smart agriculture,” “Internet of Things,” “Industry 4.0,” “Sustainable development,” “Agriculture robots,” “Cultivation,” “Decision making,” “Crops,” “Climate change,” “Soil moisture,” “Irrigation,” and “Maize,” garnered notable attention in research from 2019 to 2022. Additionally, “Plants (botany)” emerged as a research focus in 2017. Notably, the study of “Population” was identified as a supporting research area as early as 1987, while “Population dynamics”, “Industry”and “Biomass” maintained their relevance throughout the entire research period.

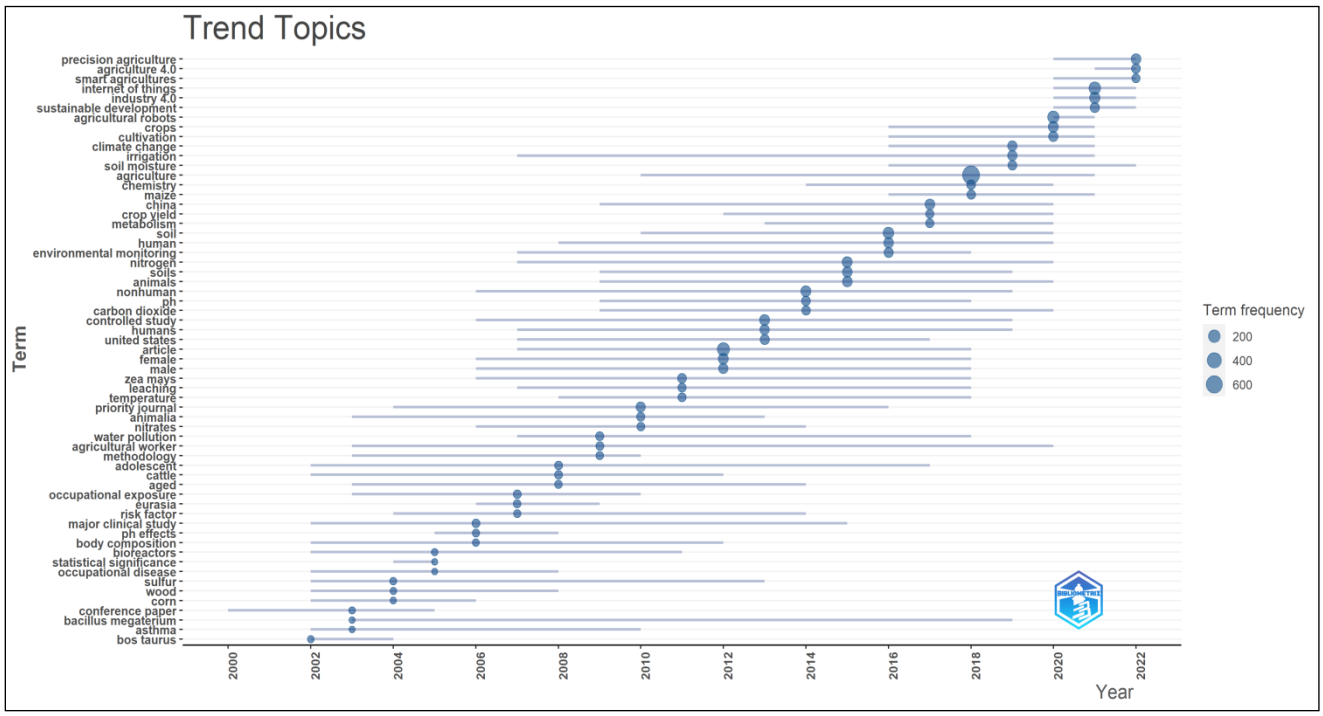


Figure 4.0 Demonstrate the Trends Topic

4.9 Conceptual Analysis: Thematic Analysis of Author Keywords

R (biblioshiny) software facilitates the creation of thematic maps, providing insights into patterns within a specific theme. It categorizes words from author keywords, keyword combinations, titles, and journal abstracts, organizing themes based on centrality and density within the text. Centrality measures the interaction between keyword networks, while density assesses internal cohesion. By evaluating centrality and density, themes can be classified into four distinct groups, offering a exact understanding of their relationships within the thematic map.The standard parameters for thematic analysis based on the Author's Keywords, a minimum number of keywords (N=250), cluster frequency (per thousand publications) (N=3), number of labels (N=5), label size (N=0.3), and the use of walk trap clustering algorithms for analysis. In the thematic map, circles represent the themes based on author keyword density. As per the Bibliometrix application, which is further divided into four quadrants.

Quadrant	Themes	Position	Details
Q1	Motor themes	Upper-right	These themes are both well developed and important for the structure of the research field
Q2	Niche themes	Upper-left	They have well-developed internal ties but unimportant external ties and so, they play a marginal role for developing the scientific field
Q3	Emerging or declining themes	Lower-left	They are both weakly developed and marginal for the research field
Q4	Basic and transversal themes	Lower-right	They are important for a research field but are not developed.

There are 250 keywords that were noted and distributed in 13 clusters, each representing a group of keywords related to similar characteristics. Themes are reflected in Figure 5, where callon centrality, callon density,rank centrality, rank density, and keyword frequency have been shown in Table 9.0. In these 13 thematic axes, we retrieved studies to contextualize and understand the themes in agriculture 4.0. On the basis of High Centrality and Density, Agriculture 4.0 and Industry 4.0 have high Callon Centrality values (0.190 and 0.170, respectively), indicating their central importance in the fields. These clusters also have moderate to high Callon Density values (4.96 and 6.68), suggesting they are well-developed areas of research with dense interconnections. Both clusters have high Cluster Frequencies, with Industry 4.0 at (N=655) and Agriculture 4.0 at (N=555), indicating their prominence and significant research interest. Remote Sensing and Climate Change have moderate Callon Centrality values (0.011 and 0.027) but high Callon Density values (7.21 and 6.28). This indicates these areas are well-connected and potentially emerging areas of research.The Cluster Frequencies (N=29) for Remote Sensing and (N=57) for Climate Change suggest they are growing areas of interest. Clusters like Water Quality, Phosphorus, Temperature, and Image Processing have high Callon Density values (ranging from 8.33 to 11.11) but a Callon Centrality of 0. This indicates they are highly specialized areas with dense internal connections but not central to the overall network. Clusters such as Yield and Irrigation have low Callon Centrality (0.005 and 0.006) and lower Callon Density values (4 and 4.166) indicating they are less central and less densely interconnected compared to others.

Table 8.0 Thematic Map of Emerging Subjects

Rank	Cluster	Callon Centrality	Callon Density	Rank Centrality	Rank Density	Cluster Frequency
1	Agriculture 4.0	0.190	4.962	13	3	555
2	Industry 4.0	0.170	6.684	12	5	655
3	Climate Change	0.027	6.280	11	4	57
4	Water Quality	0.025	8.333	10	8.5	12
5	Remote Sensing	0.011	7.212	9	6	29
6	Irrigation	0.006	4.167	8	2	24
7	Yield	0.005	4.000	7	1	25
8	Phosphorus	0.000	10.000	3.5	11	10
9	Productivity	0.000	9.091	3.5	10	11
10	Temperature	0.000	11.111	3.5	12.5	9
11	Wheat	0.000	7.692	3.5	7	13
12	Image Processing	0.000	11.111	3.5	12.5	9
13	Soil	0.000	8.333	3.5	8.5	12

Fig. 5.0 indicates the author's thematic map on agriculture 4.0. Four themes have been analysed. Motor,niche,emerging and declining and basic themes in agriculture 4.0. In motor themes quadrant 1 represents water quality, with (N=12) documents, was found most relevant.The Niche themes quadrant 2 have, 5 basic theme that is Soil with (N=12), Productivity (N=11), phosphorus (N=10), image processing (N=9) and Temperature (N=9).The basic theme, quadrant 3 have 5 basic themes first is, agriculture 4.0 with (N=201) documents, followed by precision agriculture (N=77) and smart farming (N=59); themes second represent with industry 4.0 with (N=153) documents followed by internet of things (N=87) and agriculture (N=84); third themes represented by remote sensing with (N=16) and monitoring (N=13) documents; fourth themes represent by climate change with (N=23) documents followed by food security (N=18) and sustainable development (N=14) documents and fifth theme is Irrigation with (N=24) documents. In between niche and emerging themes, the wheat (N=13) document was found to be most relevant and in-between emerging and primary themes yield with (N=25) document found most relevant subject area of research in agriculture 4.0.

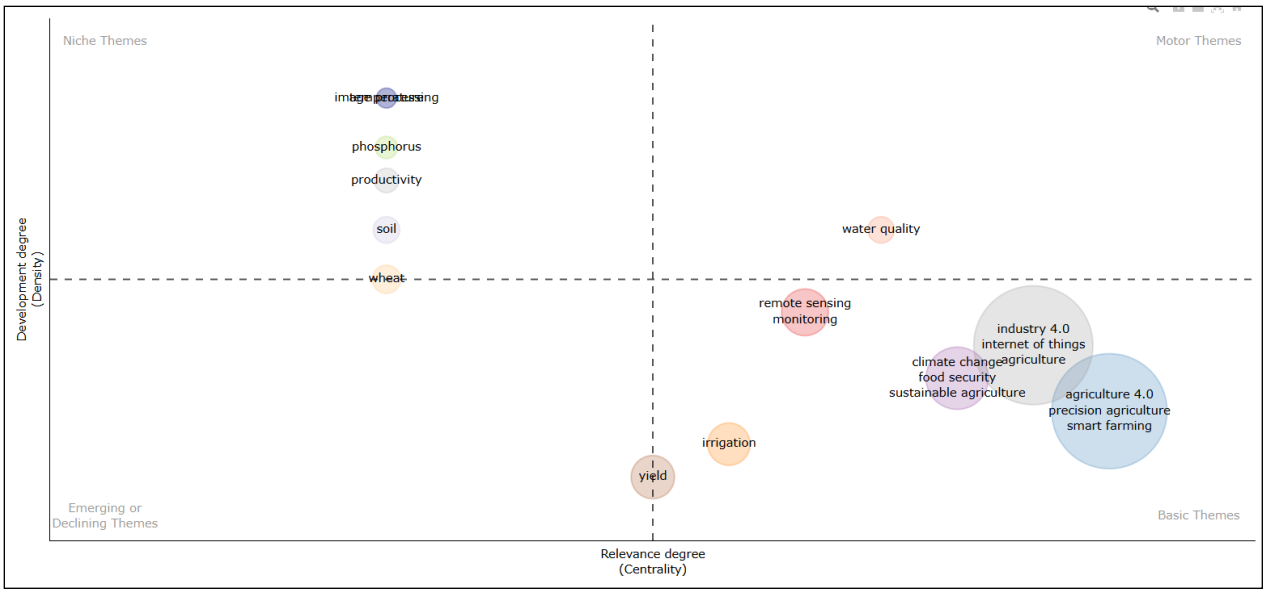


Figure 5.0 Keywords Thematic Map

4.9.1 Thematic Evolution of Keywords

Figure 6.0 demonstrates the evolution of author keywords from 1965 to 2022 and is divided into four time frames. In the first time frame of the 1965-2014 (article, agriculture and developing countries) are the most trending research topics identified. (Soil, agriculture, humans, agriculture robots, and Internet of Things) are the relevant themes during the 2015–2020 time frame. (Crops, recycling, and Escherichia coli) are the most relevant research areas from 2021 to 2022, and (Internet of Things and DNA) are recent areas of research in agriculture 4.0.Whereas article, human and agriculture are the primary research areas found during the whole study period.

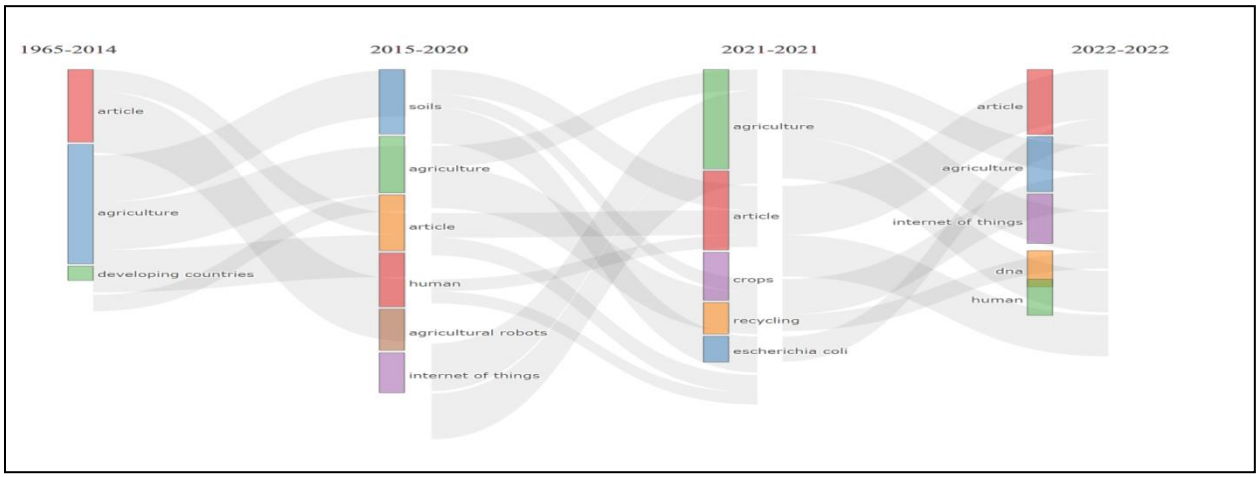


Figure 6.0. Thematic evolution of keywords

5.0 Discussion

The study examines the (N=1859) articles on agriculture 4.0, from 1965 to 2022 and sourced from the Scopus database, revealing notable trends. The literature on agriculture 4.0 experienced an annual growth rate of (N=11.03%), displaying consistent growth from 1995 to 2017, followed by a substantial exponential surge post-2017. A significant uptick in publication rates from 2019 to 2022 indicates heightened interest and research activity in this domain. The yearly citation rate varied, reaching its peak

in 2019 with (N=3980) citations, experiencing a slowdown between 2010 and 2013, and witnessing a substantial growth in citations from 2014 to 2020, followed by another slowdown.
Computers and Electronics in Agriculture emerged as the most relevant source, boasting an (N=11 h-index, N=15 g-index, and N=0.733 m-index), along with (N=15) articles and (N=861) citations. The Journal of Environmental Quality followed closely as the second most relevant source with an (N=11 h-index, N=12 g-index, and N=0.354 m-index). Li, H., noted as the most prolific author, showcased an (h-index of 8, g-index of 14, m-index of 0.47), with (N=14) publications and (N=289) citations, followed by Li, Y., with similar indices and (N=12) publications garnering (N=399) citations. The highest-cited article was Wang Y.'s (2006) study on Methylene Blue removal, with (N=226) citations, published in the Journal of Hazardous Materials. Li Y.'s (2020) work on the Construction of Au Nanoparticles received the second-highest citation score (N=150) in Biosensors and Bioelectronics. Among the (N=1,943) institutions analysed, China Agricultural University emerged as the leader with (N=67) articles, while Stuttgart secured the second position with (N=41) articles. China maintained its top position at the country level with (N=168) publications, closely followed by the USA with (N=126). However, regarding citation impact, the USA led with (N=6,773) citations, while China followed closely with (N=4,972) citations. Notably, India, ranking third in publications, dropped to the third position in terms of citation impact. Examining average citations per article, Ghana achieved the highest with (N=189), followed by the Netherlands at (N=126.4). Author keyword analysis revealed that "agriculture" was the most frequently occurring term, noted (N=799) times, followed by "articles" (N=291), "Internet of Things" (N=194) , "agriculture robot" (N=189) and "soil" (N=151). In 2022, trending topics included "Internet of Things" and "DNA," while in 2017, "Crops," "recycling," and "Escherichia coli" took centre stage. Themes like precision agriculture, agriculture 4.0, and smart agriculture dominated in 2022, while "Internet of Things," "industry 4.0," and "sustainable development" were prominent in 2021.
The thematic analysis representing 13 clusters provides a comprehensive view of Agriculture 4.0. Agriculture 4.0 and Industry 4.0 emerge as central themes with high Callon Centrality and Density values, indicating their pivotal roles and well-developed research networks. Remote Sensing and Climate Change, with moderate Callon Centrality but high Density, suggest they are well-connected and emerging research areas.Highly specialized clusters like Water Quality and Phosphorus have high Density but zero Centrality, indicating dense internal connections without broader influence. Themes such as Yield and Irrigation show low Centrality and Density, marking them as less central and interconnected.The thematic map categorizes four primary themes that are motor, niche, emerging and declining, and basic. Water quality, soil, productivity, phosphorus, image processing, and temperature are key niche themes, while basic themes like Agriculture 4.0 and Industry 4.0 are foundational. Emerging themes include wheat and yield, highlighting growing research interest.
Over time, research priorities have shifted from general agriculture and developing countries to advanced technologies like the Internet of Things and agricultural robots. This evolution underscores Agriculture 4.0's dynamic and multi-faceted research landscape, focusing on integrating advanced technologies to address contemporary challenges.This study successfully achieved its objectives, providing valuable insights into global research trends in Agriculture 4.0. The findings are a significant resource for the research community and policymakers, offering a bird's eye view of the field's evolution, impact, and thematic dynamics.

6.0 Conclusion

The study of 1,859 articles on Agriculture 4.0 from 1965 to 2022 reveals a notable growth trend, especially post-2017, highlighting a surge in research interest and activity. Central themes like Agriculture 4.0 and Industry 4.0 dominate due to their high importance and well-developed networks, while emerging areas like Remote Sensing and Climate Change gain traction. Key sources and prolific authors significantly contribute to the field's knowledge base, with China and the USA leading in publications and citations. The evolving research priorities reflect a shift towards integrating advanced technologies, addressing contemporary agricultural challenges. This study provides crucial insights for researchers and policymakers, mapping the field's dynamic landscape and thematic evolution.

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