PLANT SCIENCE TODAY
Vol x(x): xx–xx
https://doi.org/10.14719/pst.10165

eISSN 2348-1900

REVIEW ARTICLE

Exploring the impact of drone technology on agricultural practices: A bibliometric review

Prasad Koppolu[1], N Venkatesa Palanichamy[2*], A Rohini[1], M Kalpana[3], E Parameswari[4] & Kowsalya S[1]

[1]Department of Agricultural and Rural Management, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[2]Agriculture College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[3]Office of the Dean (Agriculture), Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[4]Nammazhvar Organic Farming Research Centre, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Correspondence email - nvpchamy@tnau.ac.in

Received: 20 June 2025; Accepted: 19 July 2025; Available online: Version 1.0: 26 August 2025

Cite this article: Prasad K, Venkatesa PN, Rohini A, Kalpana M, Parameswari E, Kowsalya S. Exploring the impact of drone technology on agricultural practices: A bibliometric review. Plant Science Today (Early Access). https:/doi.org/10.14719/pst.10165

Abstract

Drone technology has emerged as a transformative tool in agriculture, yet its overall impact lacks a thorough bibliometric evaluation. The study offers a detailed analysis of its applications, advantages and the challenges faced in agricultural practices. Drones or unmanned aerial vehicles (UAVs), have become essential tools in precision agriculture, enabling real-time monitoring, diseases identification, yields estimation and the precise application of fertilizers and pesticides. By integrating advanced imaging technologies and machine learning, drones enhance decision-making and optimize resource utilization in farming operations. This research employs a bibliometric approach using Biblioshiny and VOSviewer to analyze 375 articles from the Scopus database (2011–2025), identifying key research trends, influential authors and thematic clusters. The findings reveal a significant rise in agricultural drone research, particularly after 2019, driven by technology innovations and a global shift toward sustainable farming practices. Despite their potential, several barriers hinder widespread adoption-especially in developing countries. These include limited awareness among small-scale farmers, regulatory restrictions, infrastructural deficiencies, high initial costs and a shortage of skilled personnel. The review also highlights research gaps in long-term impact assessments, ethical considerations and integration with emerging technologies such as blockchain and the internet of things (IoT). To fully realize the transformative potential of drones in global agriculture, the article concludes by emphasizing the need for inclusive, context-specific solutions, enabling legislation and international collaboration.

Keywords: data-driven agriculture; precision farming; remote sensing; sustainable farming; unmanned aerial vehicles (UAVs)

Introduction

Drone technology has revolutionized conventional agriculture practices in recent years by enhancing resource utilization, sustainability and yield. In farming, unmanned aerial vehicles (UAVs), also known as drones, are increasingly being used for applications such as crop monitoring, disease detection, yield estimation for purposes and accurate fertilizer and pesticide application. As food needs in the world continue to grow and there is a need to utilize inputs to its maximum and minimize environmental degradation, this technological convergence proves helpful (1, 2). The role of the mechanistic crop simulation models in predicting the outcome of agriculture with the help of the environmental and management variables. These variables are used in models like AGROSIM and AGROTOOL which improve crop yield forecast and maximize the use of resources. Combining them with the technology of drones will allow further improving precision agriculture so that it is possible to manage crops more precisely and in real-time (3).

Drones are critical for monitoring geographical variation in crop health and field conditions due to their ability to take high-resolution, real-time images drones are critical for monitoring geographical variation in crop health and field conditions due to their ability to take high-resolution and real-time images (4). Multispectral and thermal imaging capabilities also allow for detection of both abiotic and biotic stresses at early stages, allowing swift responses (5). Drones are critical in achieving sustainable intensification or working with fewer resources and producing more, within smart agriculture and the broader digital shift in food systems (6).

Farmers can detect crop stress, disease incidence and nutritional deficiencies with high spatial and temporal accuracy using UAVs equipped with multispectral, hyperspectral, thermal and red, green and blue sensors (7, 8). The precision inherent in combining this aerial data with geographic information systems (GIS) and machine learning (ML) technologies enables the stakeholders to maximize inputs like pesticides and fertilizers at a low cost and environmental impact (9, 10). Governments and Agri-Tech sectors worldwide are supporting drones by financing the research, developing capacity and integrating the application in policies especially in areas that are susceptible to food poverty and climate changes (11).

Drones have accelerated the digitization of agriculture and created new opportunities in agronomy research and extension services, particularly where human-scale field scouting is costly and time consuming. Moreover, the integration of data collected by drones with the IoT and machine learning facilitated smarter decisions-making and predictive analytics, thereby enhancing agricultural efficiency (12). UAVs and their platforms are becoming increasingly efficient and affordable. In agriculture, drones are now being used for extended flights times, real-time kinematic (RTK), global positioning system (GPS), artificial intelligence (AI) and cloud computing application (13, 14). UAVs offers an opportunity to bridge the technological divide in resource-scarce by providing scalable affordable monitoring solutions to both developing and developed nations (15). Despite their potential, several challenges remain, including issues related to data processing, legal framework, scope of application and the availability of trained operators (16, 17).

Challenges in the adoption and implementation of drones in agriculture

Technical challenges

When it comes to using agricultural drones, reliable internet connectivity is critical in both updates, compliance and scheduling of flights. They are however limited by short flight duration and load capacity hence their coverage and functionality (18). Additional technical challenges are an absence of an effective infrastructure to process and store data, the expensive prices of the components and connectivity issues (19). The weather further limits the drone operations and to avoid misuse they require specific expertise in their implementation (20).

Operational challenges

A notable impediment is that there are no skilled pilots of drones that know of the regulations and operating protocols (21). The first is high rates of wind, which is a meteorological condition, that may also destabilize drones and filter their usage. In addition, a significant number of farms are located near restricted or no fly zones and this complicates the process of using a drone due to the presence of legal limitations (22).

Implementation challenges

The fact that drone cannot be purchased with any government incentives makes the investment inaccessible to many farmers. Current regulation rule often places powerful restrictions that discourage broader application despite them being necessary to safety (23). The fact that drone repair and maintenance centres are in absent in rural vicinity also pose significant logistical challenges (24). The development is also held back by the fact that there is no government effort behind the formulation of regulations that will allow innovation in drones and the Internet of things (25). Also, strict legislations against flying a drone in a public place pose extra limitations on the ease of taking up drones and its operations (26).

Economic challenges

The high initial costs of purchasing agricultural drones, training of personnel, acquiring expensive parts and maintaining equipment pose significant financial challenges for most farmers-particularly smallholders. These limitations hinder the adoption and accessibility of drone technologies in agriculture (27). The cost of components is not cheap yet since those that deal in drones are still at their start-up stage and government incentives and subsidies to assist in these costs are scarce. Additionally, complex regulations further slow the adoption process (28). In rural areas, the poor infrastructure and limited access to the local service centres reduce the efficiency of operations and the downtime, making it harder to fully utilize drone technology, even more so. To achieve the wider application in agriculture, drones should be both scalable and affordable and thus these infrastructural and cost issues should be resolved (29).

Knowledge and awareness gaps

Drones and IoT-based data-driven agriculture solutions are not well understood by many farmers. Because people frequently do not completely comprehend the potential benefits, this deficit prevents them from accepting and using innovative technologies (30).

Several significant research gaps still exist despite the growing collection of literature on drone uses in agriculture. First, most of the current research focuses on case-specific implementations and technological advancements in developed regions, while the adoption challenges in developing nations, such as a lack of skilled operators, cost constraints, regulatory barriers and limited digital infrastructure, remain understudied. Comparative studies between high-income and low-to-middle-income nations are lacking, which might highlight worldwide differences in the use of drones in agriculture. Moreover, while many research papers emphasize the use of drones in precision farming, there are few longitudinal studies looking at the long-term socioeconomic effects on smallholder farmers and rural communities.

Furthermore, multidisciplinary integration specifically fusing drone data with blockchain, AI and IoT for end-to-end agricultural supply chain optimization has received little attention. Ethical, privacy and data ownership concerns related to drone monitoring in agricultural operations are also not well covered in the literature. The lack of a comprehensive bibliometric synthesis that is especially focused on drone-based agricultural research, even though bibliometric studies in precision agriculture have been carried out, might highlight new themes, publishing patterns and knowledge gaps. Building contextually relevant drone solutions that are inclusive, scalable and sustainable across a range of agro-ecological and economic contexts requires addressing these issues.

Data sources

The purpose of the bibliometric study proved to investigate how AI affects human resource management. The Scopus database that which is widely used by the scientific community and is thought to be one of the biggest with over 94 million records, provided the data. However, the process for gathering materials on drone usage in agriculture is shown in Fig. 1.

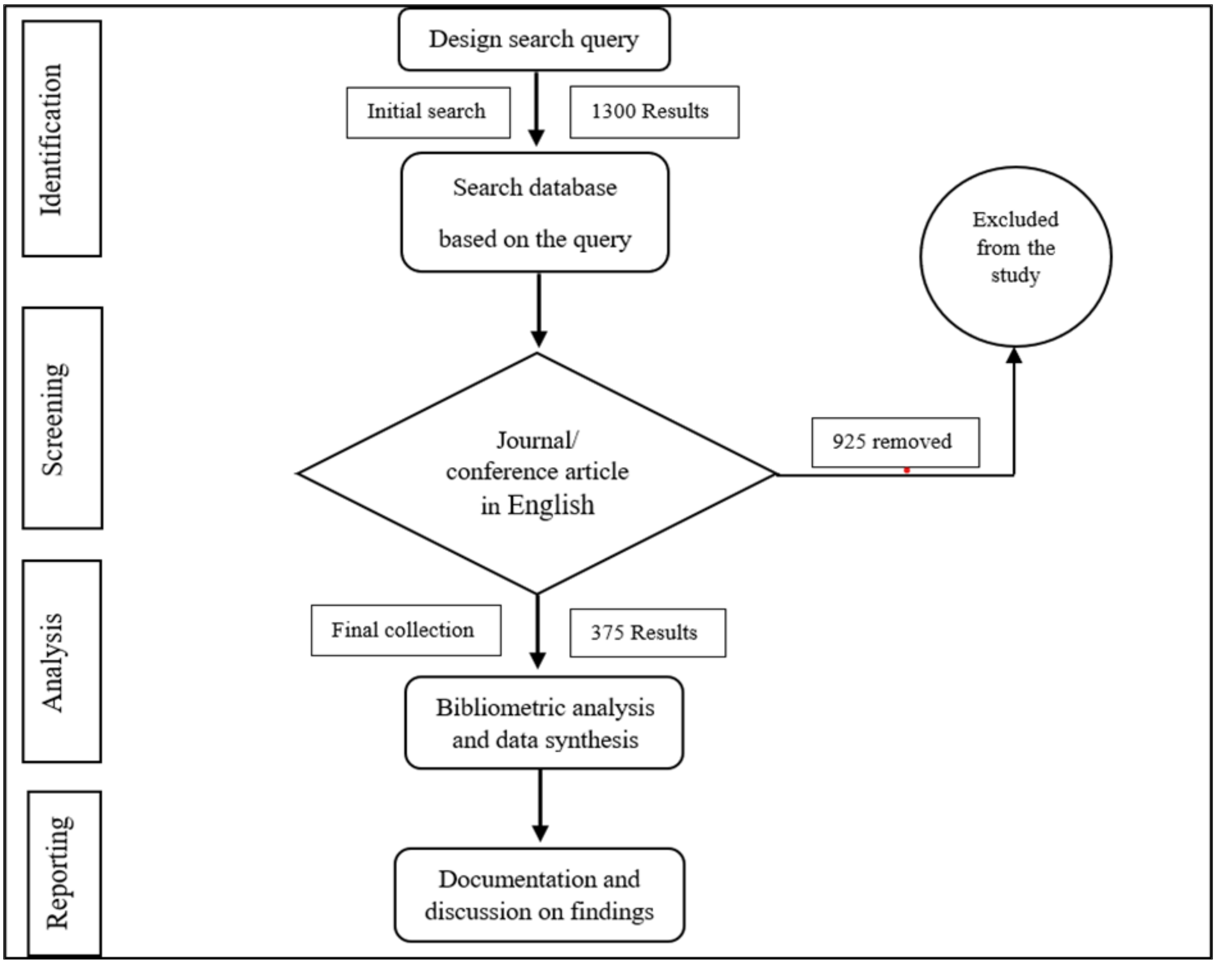

Fig. 1. Recommended reporting things for bibliometric analysis using the systematic reviewing and meta-analysis (PRISMA) framework.

PRISMA (preferred reporting items for systematic reviews and meta-analyses) provides a transparent, replicable and reproducible framework to perform systematic reviews in a clear and organized manner (with regards to search methodology, selection criteria and explanations regarding rejections). It improves the reliability of reviews through minor bias and making the documentation detailed and clear. The framework however is time consuming and complicated especially when conducting massive reviews. Also, the rigid design will not work with any type of review like scoping or narrative review, not leaving room to be flexible. The PRISMA has a purpose to reduce the bias, it could still have the publication bias because unpublished research may get ignored.

Data collection and analysis

Using the Boolean operators AND & OR, articles on the use of drones in agriculture were collected based on specific keywords. The research was conducted using the terms "*drone*" and "*agriculture*", targeting abstracts, titles and article-specific keywords. This method yielded approximately 1300 results. After applying various filters to ensure relevance and quality, 375 articles were selected for bibliometric analysis. The research focused on publications from the period 2011 -to 2025, covering themes such as agriculture, engineering and environmental science. Further restricted the dataset to English-language journal articles, making the analysis more consistent and easier to interpret. To narrow the scope of the study, keywords such as precision agriculture, drones, agriculture robots, remote sensing, crops and aerial vehicles were used. Additionally, the search was refined to include only journal publications, with preference of those offering open access, to ensure transparency and data availability.

Using R software, all duplicate and irrelevant papers were eliminated from the study. The researcher studied the abstracts of the articles and chose a few depending on the pertinent information required for the study. The chosen articles were loaded into the Biblioshiny program using R Studio after being exported to a comma separated value (CSV) file. VOSviewer, a visualization program, was utilized to assess the study's findings and Biblioshiny software was used for the quantitative analysis. Performance analysis and science mapping were the two categories into which Biblioshiny's analysis was separated.

Performance analysis provides information about the elements of the study by using published facts. The outcome of the study used metrics like average citations (AC), total publications (TP), total citations (TC) and indices like the h-, m- and g-indices. Science mapping makes use of metrics such as bibliographical coupling, citations evaluation, author keywords evaluation, top-cited publications and others. This promotes the growth of the intellectual framework of the selected study. This supports the development of the chosen study's intellectual framework.

Significance of bibliometric analysis

In recent years, researchers from several fields have come to recognize the value of bibliometric investigations (31). Bibliometric software like Biblioshiny, VOSviewer software and Leximancer draws a lot of focus (32). Researchers can uncover concealed domains that conventional analysis, such as systematic literature review (SLR), cannot reach with the aid of bibliometric analysis (33). Bibliometric analysis relies on quantitative methods, while SLR relies only on qualitative methods, which can generate biased results. This is the primary difference between the two types of analysis.

Annual scientific production

Research on drone applications in agriculture has grown steadily since 2016, with a sharp rise from 2019 onwards. The number of publications peaked in 2023 with over 90 articles, reflecting increased interest in drone-based precision farming and remote sensing. Although a slight drop is seen in 2024, the overall trend highlights the growing importance of drones in enhancing agricultural productivity and sustainability (Fig. 2).

Most relevant sources on Bradford's law

Selecting relevant articles from reputable journals is crucial for a substantial increase in knowledge. Because there is so much information available, selecting a reliable and instructive sources to learn about the most recent developments in each field can be dangerous. Therefore, to learn more about the most recent material on a given topic, it is important to separate the main journals. Bradford's law, which at first is founded on the idea of dispersion, states that articles are separated to core zones that show the importance of their sources. While the other areas are not as likely to be cited, the core zone highlights the pertinent and effective sources that receive the most citations. Bradford's law is therefore used to pinpoint the in each field (34). Bradford's law states that the primary journals that have made significant contributions to the study of drone applications in agriculture are listed in Fig. 3.

The major sources are agronomy, computers and electronics in agriculture, agriculture (Switzerland), remote sensing and sensors. These publications, which together make up the core zone, publish a significant number of excellent and peer-reviewed articles in this area. For example, remote sensing and sensors have each published more than 30 publications, indicating their leadership in sharing state-of-the-art research on agricultural technology based on UAVs. These fundamental resources provide crucial insights into subjects including precision spraying, multispectral imaging, crop monitoring and remote sensing, making them indispensable points of reference for scholars and professionals. Researchers may expedite their literature reviews and promote evidence-based research in drone technology and agricultural innovation by identifying these important periodicals.

The most related writers and their influence locally

The importance of increasing authors' visibility has increased in the age of digital transformation. Recently, the development of online profiles for researchers has made digital object identifiers (DOIs) an important element of performance evaluation (35). Similarly, several indicators are used to assess

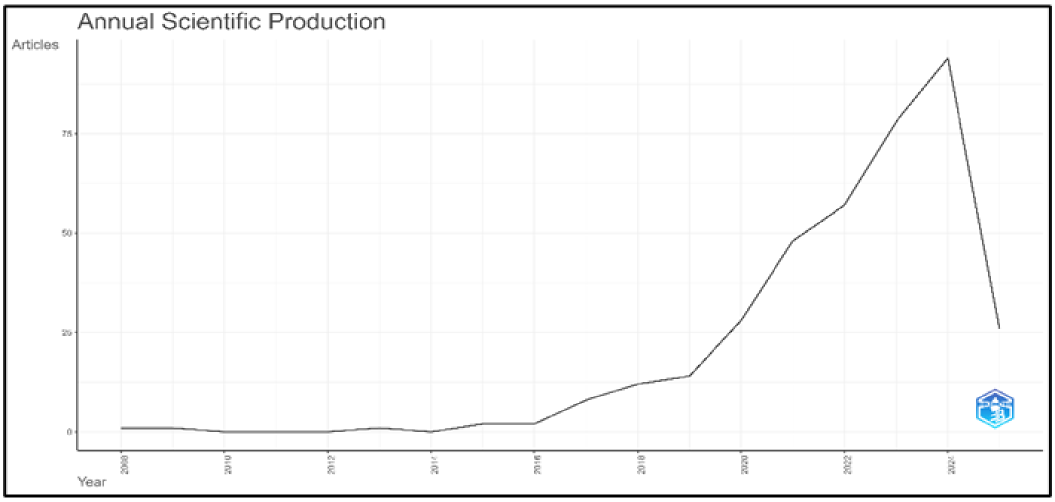

Fig. 2. Annual scientific production of drone technology in agricultural research.

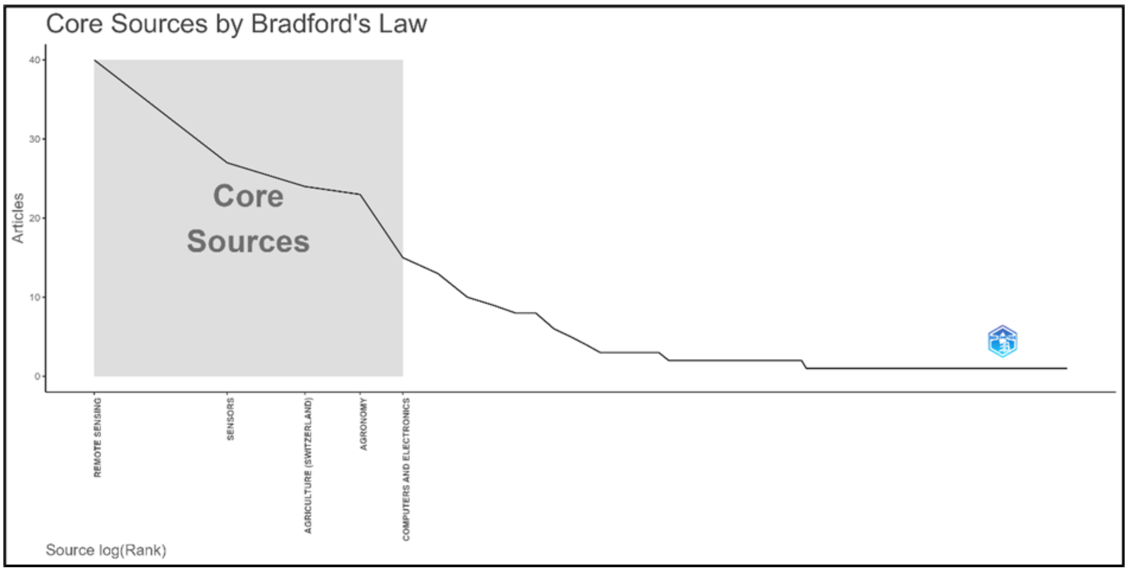

Fig. 3. Core sources in drone technology research according to Bradford's law.

the author's study. The h, g and m indices were the most widely used; the majority of research evaluations use the h index the most (36). The h index, which gives each publication by a specific author equal weight, is calculated by adding up all of the articles and citations to those publications (37). The h index's primary drawback is its inability to compare data from various disciplines or research areas and its inability to distinguish between different work quality levels.

This leads to the discovery of another index, called the g index, which is better than the h index. The calculation of this index involves giving highly cited articles greater significance and low-cited papers less credit (38).

Table 1 provides insights into the local academic impact of top researchers in the field of drone applications in agriculture. Among the leading contributors, Kaivosoja J, Jagarlapudi A and Raj R have demonstrated significant influence based on bibliometric indicators. Kaivosoja J stood out with a total citation count of 228, the highest among the authors, despite publishing only 3 articles. His consistent h index and g index of 3, along with an m index of 0.375, reflect a concentrated impact within a short time. Jagarlapudi A has contributed 5 publications to the domain, achieving an h index of 3, g index of 5 and an m index of 0.6, with 97 citations, indicating both quantity and quality in research outputs. Similarly, Raj R, with 4 articles, has attained a g index of 4, an h-index of 3 and an m-index of 0.6, accumulating 96 citations demonstrating consistent performance in drone-related agricultural research. These authors are recognized as key influencers in the domain, providing valuable contributions that advance the understanding and implementation of drone technologies in agricultural practices.

Most influential documents

A research trend for the specific study period can be obtained from the data on local and global cited documents. In general, citations collected from an article across the full database without a filter will be referred to as global citations. On the other hand, when filtration is present, local citations referred to the article's citations; that is, while globally cited articles determine the impact across multiple fields, locally cited papers identify the impact within a specific field. As a result, assessing locally and globally cited articles improves our perception of the actual impact of research. As a result, there will always be more worldwide citations than regional ones (49). The most influential documents on the Drone applications in Agriculture during the study period are given in Table 2.

Countries' scientific production and the most cited countries

Fig. 4 presents the citation impact of different countries in the field of drone applications in agriculture. The United States, Italy and Germany emerged as the top three most cited countries, indicating their strong research output and influence in this domain. The USA led with a total of 785 citations, followed closely by Italy with 742 citations and Germany with 565 citations. Other notable contributors included China (447 citations), Finland (406 citations) and Spain (392 citations), reflecting significant academic engagement in the adoption and technological development of drones for agricultural purposes. Countries such as the United Kingdom, Belgium, Australia and Netherlands also contributed meaningfully, with citations ranging from 370 to 271, indicating growing international interest and collaboration in precision agriculture and drone-based research solutions.

Table 1. Local impact of relevant authors in drone technology and agricultural practices

S. No.	Authors	Articles	h index	g index	m index	Total citations	Author's background	Reference
1	Liu Y	6	4	5	0.500	29	Non-agriculture (engineering)	(39)
2	Ayamga M	3	3	3	0.600	91	Agriculture	(40)
3	Costa C	3	3	3	0.500	38	Non-agriculture (engineering)	(41)
4	Du X	3	3	3	1.500	16	Non-agriculture (engineering)	(42)
5	Figorilli S	3	3	3	0.500	38	Non-agriculture (engineering)	(43)
6	Jagarlapudi A	5	3	5	0.600	97	Non-agriculture (engineering)	(44)
7	Kaivosoja J	3	3	3	0.375	228	Non-agriculture (engineering)	(45)
8	Pallottino F	3	3	3	0.500	38	Non-agriculture (engineering)	(46)
9	Pingale R	3	3	3	0.600	93	Non-agriculture (engineering)	(47)
10	Raj R	4	3	4	0.600	96	Non-agriculture (engineering)	(48)

Table 2. Most globally cited documents on drone technology and agricultural practices

Documents	Digital Object Identifier	Year	Global citation	Specific area of research & application	Reference
Zahawi RA, 2015, Biol Conserv.	https://doi.org/10.1016/j.biocon.2015.03.031	2015	232	Specific area of research & application	(50)
Huuskonen J, 2018, Comput Electron Agric.	https://doi.org/10.1016/j.compag.2018.08.039	2018	187	Precision agriculture, decision support systems	(51)
Jakob S, 2017, Remote Sens.	https://doi.org/10.3390/rs9010088	2017	176	Remote sensing, precision agriculture	(52)
Gnädinger F, 2017, Remote Sens.	https://doi.org/10.3390/rs9060544	2017	157	Remote sensing, agricultural technology	(53)
Latif G, 2022, Plants.	https://doi.org/10.3390/plants11172230	2022	153	Agricultural sciences, crop management	(54)
Reedha R, 2022, Remote Sens.	https://doi.org/10.3390/rs14030592	2022	153	Remote sensing, precision agriculture	(55)
Almalki FA, 2021, Sustainability.	https://doi.org/10.3390/su13115908	2021	149	Sustainable agriculture, precision agriculture	(56)
Gallo I, 2023, Remote Sens.	https://doi.org/10.3390/rs15020539	2023	146	Remote sensing, agricultural monitoring	(57)
Mesas-carrascosa Fj, 2015, Remote Sens.	https://doi.org/10.3390/rs71012793	2015	141	Remote sensing, agricultural applications	(58)
Näsi R, 2018, Remote Sens.	https://doi.org/10.3390/rs10071082	2018	140	Remote sensing, agricultural robotics and precision agriculture	(59)

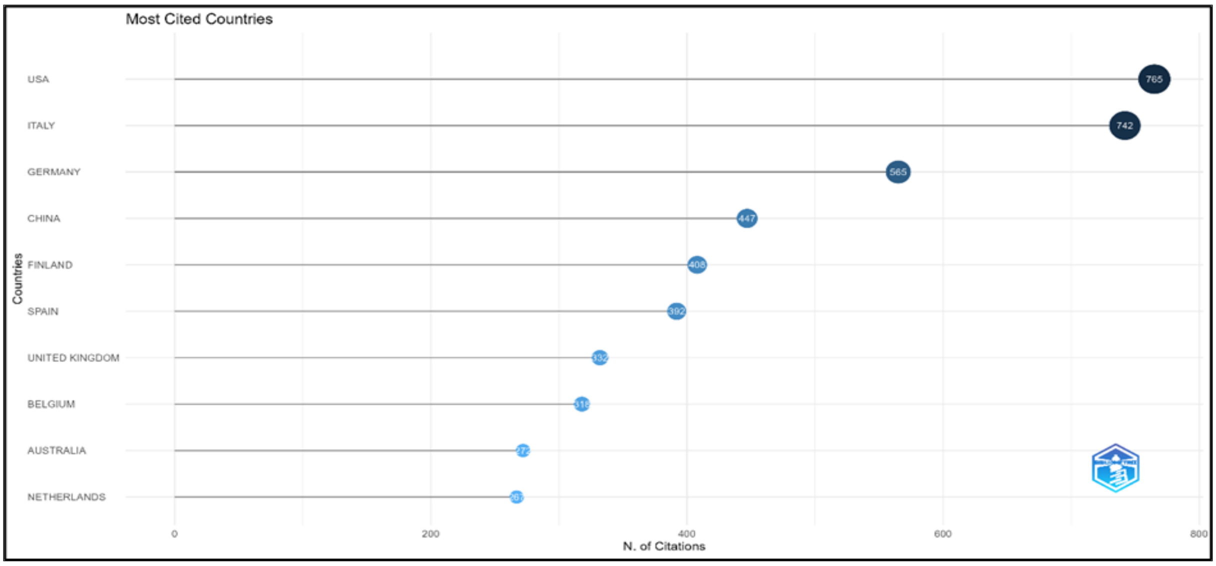

Fig. 4. Most cited countries in drone technology research.

Word cloud

Fig. 5 highlights the most frequently occurring keywords in the field of drone applications in agriculture, offering insight into the main ideas and areas of research interest. Prominent among these are terms such as “precision agriculture”, “drones”, “remote sensing” and “agriculture”, which appear most frequently and indicate the central role of drone technology in enhancing farming practices. Other significant keywords include “unmanned aerial vehicles (UAV)”, “antennas”, “machine learning” and “deep learning”, reflecting the technological convergence of AI and aerial systems in data collection, monitoring and decision-making.

Concepts such as “agricultural robots”, “crop yield”, “aerial photography” and “satellite imagery” further demonstrate the expanding applications of drones in agricultural productivity, environmental monitoring and land management. These keywords collectively underscore the interdisciplinary nature of research in this area, integrating elements of computer science, engineering and agronomy to advance sustainable and data-driven farming solutions.

Thematic map

The thematic mapping's bubbles indicate the presence of network clusters according to Callon's centrality and density rankings (60). The X axis displays the centrality, which indicates the importance of the research question. The primary strength and theme development of the study are indicated by its density (development degree) upon Y axis. Four quadrants have been defined with the use of thematic mapping. With high centrality and high density, the motor theme in the first quadrant shows that the ideas were well developed and crucial in developing the topic. With low centrality and high density, the second quadrant's niche theme indicates that its significance to the subject is restricted. The designs found in the third quadrant, which stand for that emerged or lowering themes, weren't fully developed, as indicated by the low centrality and low density. High centrality and low density characterize the most significant themes within the fourth quadrant, which represent the fundamental network clusters needed for the study (61).

Fig. 6 presents a thematic map that categorizes keywords into four clusters based on their centrality (relevance) and density (development), reflecting the structure and evolution of research on drone applications in agriculture. In the motor themes quadrant, highly developed and important topics such as “drones”, “remote sensing” and “antennas” are evident, indicating their core role in the field’s advancement. Closely aligned are terms like “agriculture”,

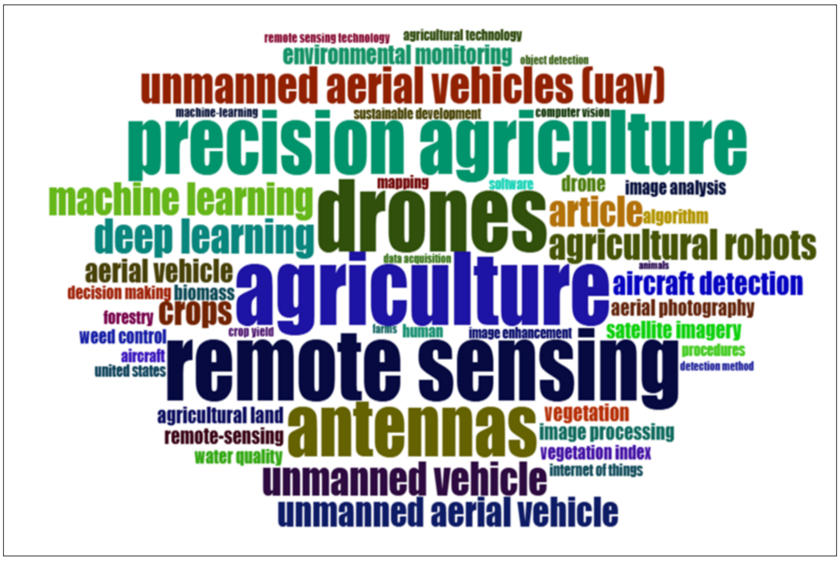

Fig. 5. Word cloud representing key terms in drone technology and its impact on agricultural practices.

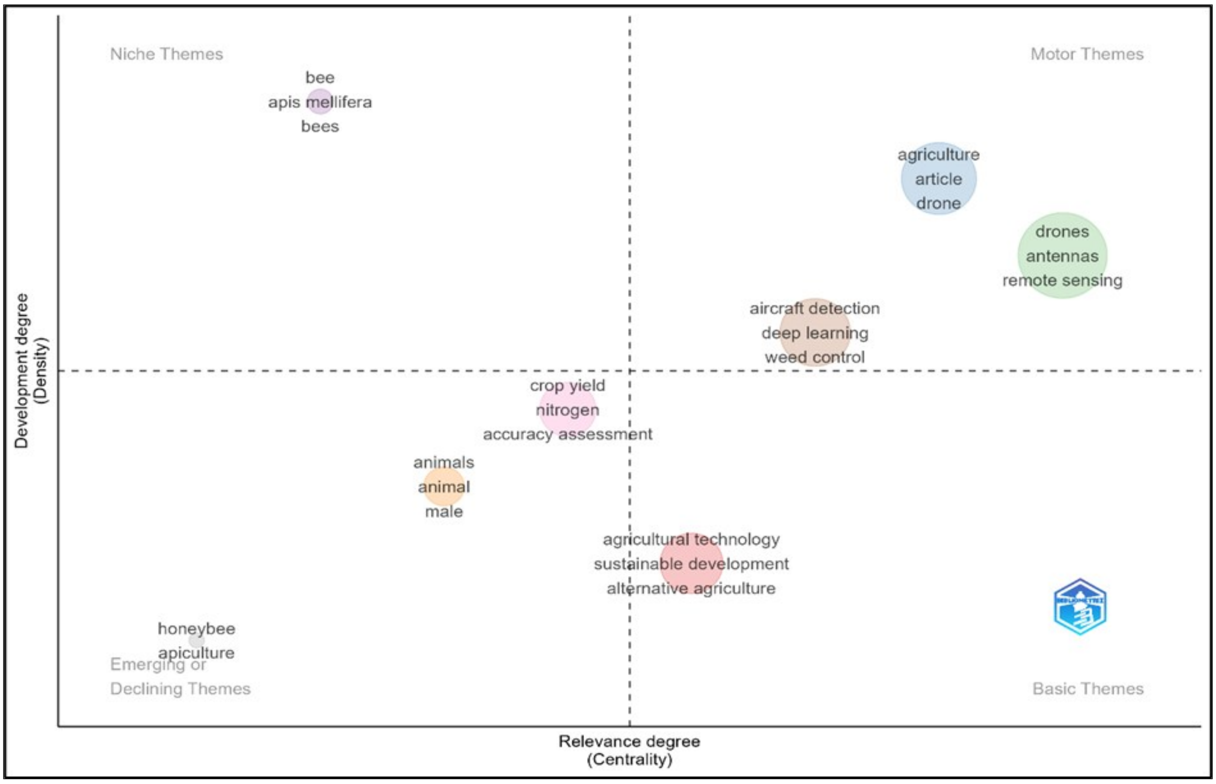

Fig. 6. Thematic mapping analysis of drone technology in agricultural research.

"article" and "drone", which also hold strong relevance and development, demonstrating their consistent integration in scholarly discourse.

Conversely, the basic themes quadrant includes keywords like "agricultural technology", "sustainable development" and "alternative agriculture" which, although foundational, show lower density and may benefit from further empirical exploration. The niche themes, such as "bee" "Apis mellifera" and "bees" appear to be well-developed yet limited in their broader relevance to the drone-agriculture research network. Meanwhile, emerging or declining themes like "honeybee" and "apiculture" reflect areas either in early exploration or losing academic focus.

Future research should build upon the established motor themes while integrating underexplored areas such as deep learning, aircraft detection and weed control to enrich the field's methodological depth and application diversity. In Fig. 6, key themes of precision agriculture on crop yield in the USA, UK and Germany and are shown as crop yield, drones and remote sensing. Agricultural technology in these countries focuses on improving farming and related processes and agricultural activities, as the USA is the leader in applying drones and GPS-guidelines systems to enhance the crop productivity. UK concentrates on sustainable agriculture and Germany uses precision irrigation and improved equipment to improve productivity. On the formatted map, it is easy to see how the use of technology is helping these countries to enhance sustainability and efficiency in the yields.

Bibliometric coupling

Bibliometric coupling is a kind of science mapping technique where publications with similar content share common references. In this study, publications from the selected periods were categorized into different categories. The nations of origin, co-word analysis, author and keywords were used to generate these clusters.

Each node in bibliometric coupling indicates an object and size of the node indicates how many times the object appeared throughout the study period. Nodal connections show that the contents occurred simultaneously between the two connected sites and their density shows how often they occurred together. Different colors are used to distinguish each cluster, which represents the coverage of a certain area chosen for the research project.

Fig. 7 illustrates the bibliometric coupling among countries engaged in research on drone applications in agriculture. The map reveals the existence of collaborative linkages primarily among five key countries, namely the USA, UK, Germany, Uruguay and Peru. The USA, UK and Germany are central players in the global research network, indicating strong academic output and interconnectivity through shared citations and research foundations. On the other end, Uruguay and Peru represent emerging contributors forming a distinct cluster with moderate collaboration intensity.

The color gradient reflects the strength and direction of citation-based links, with red denoting stronger internal connections within high-output nations and green indicating growing cooperation in emerging regions. This coupling map showcases the global diffusion of knowledge, highlighting how drone technology research in agriculture is not only concentrated in technologically advanced countries but is also gaining traction in developing regions, promoting international collaboration in precision farming and agricultural innovation. Fig. 7 depicts bibliometric coupling of precision agriculture studies in USA, UK and Germany.

The close connections of such themes as "drones", "agricultural technology" and "crop yield" point to the fact that these countries are looking into ways of enhancing efficiency and productivity in agriculture through technological

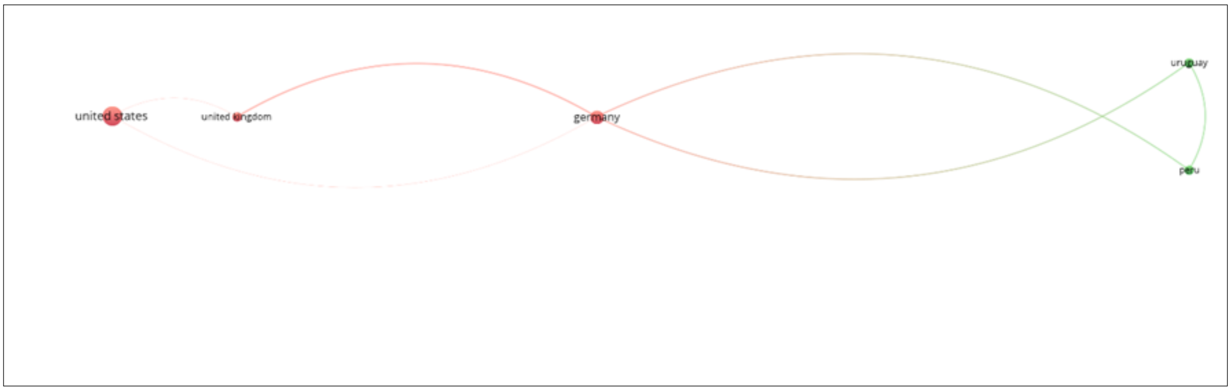

Fig. 7. Bibliographic coupling of nations. Source: utilizing on the VOSviewer's analysis, the author drawn.

breakthroughs. The given analysis demonstrates that the research conducted in these countries is interrelated and there are some shared themes which stimulate productivity growth and sustainability of farming methods.

Fig. 8 categorizes the most relevant keywords into seven thematic clusters, illustrating the diverse research directions within the domain of drone applications in agriculture. Terms like "machine learning", "fertilizers", "canopy structure" and "field crops" are included in the green clusters, which reflects the incorporation of AI to maximize crop surveillance and input management. The red cluster centers around keywords like “drone”, “backscatter” and “cost effectiveness” emphasizing economic evaluations and sensor-based drone performance.

The blue cluster focuses on operational terms such as “drones”, “vegetation index” and “aerial vehicle” indicate high-frequency studies on remote sensing and crop assessment. The violet cluster features “precision agriculture”, “mapping” and “aerial photogrammetry” highlighting efforts toward spatial analysis and data-driven farming practices. In the yellow cluster, “satellite imagery” serves as a bridge between agricultural application studies and regional case analysis, such as “Ayacucho”. The orange cluster includes niche applications like “high-resolution mapping”, while the light blue cluster connects keywords such as “artificial intelligence” and “crop yield” pointing to predictive and decision-support capabilities of drone-integrated systems. Among all, frequently occurring keywords such as “drones”, “precision agriculture”, “vegetation index” and “machine learning” dominate the landscape, reflecting their central role in the scholarly exploration of drone technology for agricultural innovation and sustainability.

Conclusion

Drone technology is emerging as a powerful tool in agriculture, offering benefits such as precision input application, yield estimation, crop monitoring and disease detection, contributing to more efficient and sustainable farming practices. A bibliometric review highlights a surge in research interest, particularly after 2019, driven by advances in artificial intelligence, machine learning and sensor technologies. However, widespread adoption remains limited, especially in developing countries, due to challenges like high costs, lack of skilled personnel, regulatory barriers and inadequate infrastructure. The review identifies key research gaps, including the need for long-term studies on socioeconomic impacts, ethical considerations and integration with technologies like IoT and blockchain. For countries like India, government support through subsidies, training programs and public-private partnerships is essential to promote drone adoption among small and marginal farmers. Special attention to crops like tea can further enhance productivity and sustainability through precision agriculture. Access to microcredit and data-driven decision-making tools can empower farmers, enabling developing nations to unlock the full potential of drone-based solutions for agricultural and environmental advancement.

Authors' contributions

PK has written the draft of manuscript. KS helped to carry out the analysis. NVP, AR, MK and EP guided, provided technical support to write the manuscript in a proper format and approved the final manuscript. All authors read and approved the final manuscript.

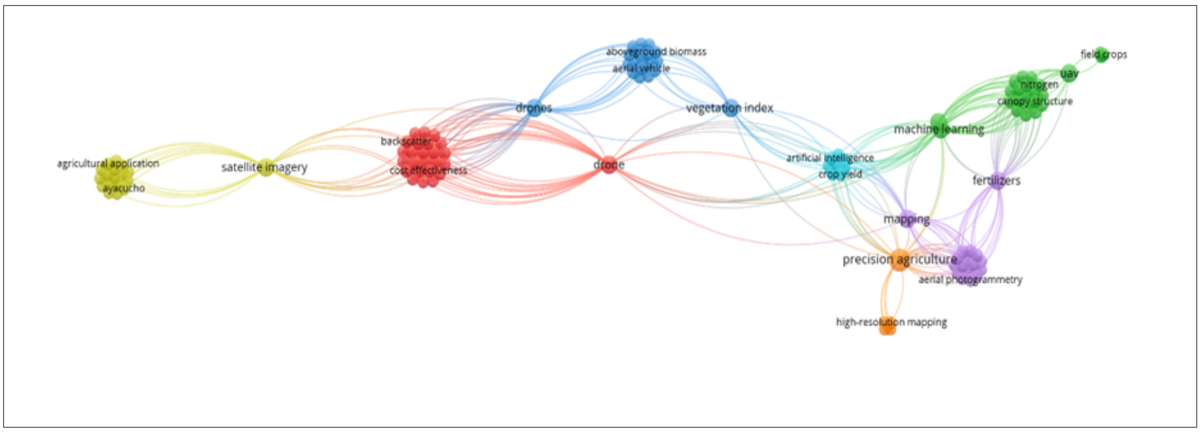

Fig. 8. Coupling the author’s keywords bibliographically. Source: utilizing the VOSviewer's analysis, the author drew.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflicts of interest to declare.

Ethical issues : None

Declaration of generative AI and AI-assisted technologies in the writing process : While preparing this work, the authors used the Grammarly AI tool to improve grammar and increase the article's readability. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of publication.

References

1. Zhang C, Kovacs JM. The application of small unmanned aerial systems for precision agriculture: A review. Precision Agric. 2012;13:693–712. https://doi.org/10.1007/s11119-012-9274-5
2. Tsouros DC, Bibi S, Sarigiannidis PG. A review on UAV-based applications for precision agriculture. Information. 2019;10(11):349. https://doi.org/10.3390/info10110349
3. Topaj A, Mirschel W. Abnormal shapes of production function: Model interpretations. Comput Electron Agric. 2018;145:199–207. https://doi.org/10.1016/j.compag.2017.12.039
4. Bendig J, Bolten A, Bennertz S, Broscheit J, Eichfuss S, Bareth G. Estimating biomass of barley using crop surface models (CSMs) derived from UAV-based RGB imaging. Remote Sens. 2014;6 (11):10395–412. https://doi.org/10.3390/rs61110395
5. Cuaran J, Leon J. Crop monitoring using unmanned aerial vehicles: A review. Agric Rev. 2021;42(2):121–32. https://doi.org/10.18805/ag.R-180
6. dela Torre DMG, Gao J, Macinnis-Ng C. Remote sensing-based estimation of rice yields using various models: A critical review. Geo-Spatial Info Sci. 2021;24(4):580–603. https://doi.org/10.1080/10095020.2021.1936656
7. Maes WH, Steppe K. Perspectives for remote sensing with unmanned aerial vehicles in precision agriculture. Trends Plant Sci. 2019;24(2):152–64.
8. Hunt Jr ER, Daughtry CST. What good are unmanned aircraft systems for agricultural remote sensing and precision agriculture? Int J Remote Sens. 2018;39(15–16):5345–76. https://doi.org/10.1080/01431161.2017.1410300
9. Mogili UMR, Deepak B. Review on application of drone systems in precision agriculture. Procedia Comput Sci. 2018;133:502–09. https://doi.org/10.1016/j.procs.2018.07.063
10. Adão T, Hruška J, Pádua L, Bessa J, Peres E, Morais R, et al. Hyperspectral imaging: A review on UAV-based sensors, data processing and applications for agriculture and forestry. Remote Sens. 2017;9(11):1110. https://doi.org/10.3390/rs9111110
11. Gano B, Bhadra S, Vilbig JM, Ahmed N, Sagan V, Shakoor N. Drone-based imaging sensors, techniques and applications in plant phenotyping for crop breeding: A comprehensive review. Plant Phenome J. 2024;7(1):e20100. https://doi.org/10.1002/ppj2.20100
12. Acharya BS, Bhandari M, Bandini F, Pizarro A, Perks M, Joshi DR, et al. Unmanned aerial vehicles in hydrology and water management: Applications, challenges and perspectives. Water Resour Res. 2021;57(11):e2021WR029925. https://doi.org/10.1029/2021WR029925
13. Peña JM, Torres-Sánchez J, de Castro AI, Kelly M, López-Granados F. Weed mapping in early-season maize fields using object-based analysis of unmanned aerial vehicle (UAV) images. PLoS One. 2013;8 (10):e77151. https://doi.org/10.1371/journal.pone.0077151
14. Tokekar P, Vander Hook J, Mulla D, Isler V. Sensor planning for a symbiotic UAV and UGV system for precision agriculture. IEEE Trans Robotics. 2016;32(6):1498–511. https://doi.org/10.1109/TRO.2016.2603528
15. Balkrishna A, Pathak R, Kumar S, Arya V, Singh SK. A comprehensive analysis of the advances in Indian digital agricultural architecture. Smart Agric Technol. 2023;5:100318. https://doi.org/10.1016/j.atech.2023.100318
16. Omia E, Bae H, Park E, Kim MS, Baek I, Kabenge I, et al. Remote sensing in field crop monitoring: A comprehensive review of sensor systems, data analyses and recent advances. Remote Sens. 2023;15 (2):354. https://doi.org/10.3390/rs15020354
17. Zualkernan I, Abuhani DA, Hussain MH, Khan J, ElMohandes M. Machine learning for precision agriculture using imagery from unmanned aerial vehicles (UAVS): A survey. Drones. 2023;7(6):382. https://doi.org/10.3390/drones7060382
18. Pathak H, Kumar G, Mohapatra SD, Gaikwad BB, Rane J. Use of drones in agriculture: Potentials, problems and policy needs. ICAR-National Institute of Abiotic Stress Management. 2020;300:4–15.
19. Sah B, Gupta R, Bani-Hani D. Analysis of barriers to implement drone logistics. Int J Logistics Res Appl. 2021;24(6):531–50. https://doi.org/10.1080/13675567.2020.1782862
20. Puppala H, Peddinti PRT, Tamvada JP, Ahuja J, Kim B. Barriers to the adoption of new technologies in rural areas: The case of unmanned aerial vehicles for precision agriculture in India. Technol Soc. 2023;74:102335. https://doi.org/10.1016/j.techsoc.2023.102335
21. Schmidt R, Schadow J, Eißfeldt H, Pecena Y. Insights on remote pilot competences and training needs of civil drone pilots. Transp Res Procedia. 2022;66:1–7. https://doi.org/10.1016/j.trpro.2022.12.001
22. Hoek Spaans R, Drumond B, van Daalen KR, Rorato Vitor AC, Derbyshire A, Da Silva A, et al. Ethical considerations related to drone use for environment and health research: A scoping review protocol. PLoS One. 2024;19(1):e0287270. https://doi.org/10.1371/journal.pone.0287270
23. Zuo A, Wheeler SA, Sun H. Flying over the farm: Understanding drone adoption by Australian irrigators. Precis Agric. 2021;22 (6):1973–91. https://doi.org/10.1007/s11119-021-09821-y
24. Raj A, Sah B. Analyzing critical success factors for implementation of drones in the logistics sector using grey-DEMATEL based approach. Comput Ind Eng. 2019;138:106118. https://doi.org/10.1016/j.cie.2019.106118
25. Sharma M, Hema N. Comparison of agricultural drones and challenges in implementation: A Review. In: 2021 7th International Conference on Signal Processing and Communication (ICSC). IEEE; 2021. p. 26–30. https://doi.org/10.1109/ICSC53193.2021.9673491
26. Da Silveira F, Lermen FH, Amaral FG. An overview of agriculture 4.0 development: Systematic review of descriptions, technologies, barriers, advantages and disadvantages. Comput Electron Agric. 2021;189:106405. https://doi.org/10.1016/j.compag.2021.106405
27. Rejeb A, Abdollahi A, Rejeb K, Treiblmaier H. Drones in agriculture: A review and bibliometric analysis. Comput Electron Agric. 2022;198:107017. https://doi.org/10.1016/j.compag.2022.107017
28. Freeman PK, Freeland RS. Agricultural UAVs in the US: Potential, policy and hype. Remote Sens Appl. 2015;2:35–43. https://doi.org/10.1016/j.rsase.2015.10.002
29. Elijah O, Rahman TA, Orikumhi I, Leow CY, Hindia MHDN. An overview of Internet of Things (IoT) and data analytics in agriculture: Benefits and challenges. IEEE Internet Things J. 2018;5 (5):3758–73. https://doi.org/10.1109/JIOT.2018.2844296
30. Rao B, Gopi AG, Maione R. The societal impact of commercial drones. Technol Soc. 2016;45:83–90. https://doi.org/10.1016/j.techsoc.2016.02.009
31. Donthu N, Kumar S, Mukherjee D, Pandey N, Lim WM. How to conduct a bibliometric analysis: An overview and guidelines. J Bus Res. 2021;133:285-96. https://doi.org/10.1016/j.jbusres.2021.04.070

32. Jesson J, Lacey FM, Matheson L. Doing your literature review: Traditional and systematic techniques; 2011.

33. Ellegaard O, Wallin JA. The bibliometric analysis of scholarly production: How great is the impact? Scientometrics. 2015;105:1809–31. https://doi.org/10.1007/s11192-015-1645-z

34. Gasparyan AY, Yessirkepov M, Duisenova A, Trukhachev VI, Kostyukova EI, Kitas GD. Researcher and author impact metrics: Variety, value and context. J Korean Med Sci. 2018;33(18):e139. https://doi.org/10.3346/jkms.2018.33.e139

35. Ayaz S, Masood N. Comparison of researchers' impact indices. PLoS One. 2020;15(5):e0233765. https://doi.org/10.1371/journal.pone.0233765

36. Hirsch JE. An index to quantify an individual's scientific research output. Proc Nat Acad Sci. 2005;102(46):16569–72. https://doi.org/10.1073/pnas.0507655102

37. Egghe L. Theory and practise of the g-index. Scientometrics. 2006;69(1):131–52. https://doi.org/10.1007/s11192-006-0144-7

38. Merigó JM, Yang JB. A bibliometric analysis of operations research and management science. Omega (Westport). 2017;73:37–48. https://doi.org/10.1016/j.omega.2016.12.004

39. Liu Y, Zhang Y, Bai Y. Applications of UAV-based remote sensing in precision agriculture: A review. Comput Electron Agric. 2020;170:105251. https://doi.org/10.1016/j.compag.2020.105251

40. Ayamga M, Tekinerdogan B, Kassahun A. Exploring challenges posed by drone regulations in African agriculture. Land. 2021;10(2):164. https://doi.org/10.3390/land10020164

41. Costa C, Antonucci F, Pallottino F, Aguzzi J, Sun D, Menesatti P. A review on agri-technologies based on UAVs. Sensors. 2020;20(18):5176. https://doi.org/10.3390/s20185176

42. Du X, Wang X, Li M, Li C. UAV remote sensing and AI in agriculture. Remote Sens. 2022;14(5):1123. https://doi.org/10.3390/rs14051123

43. Figorilli S, Antonucci F, Costa C, Pallottino F, Raso L. Blockchain traceability using UAVs in wood supply chains. Sensors. 2019;19(3):683. https://doi.org/10.3390/s19030683

44. Jagarlapudi A, Yellapu A, Maddi S. UAV-based crop monitoring using ML image processing. Agric Res J. 2023;60(1):11–18.

45. Kaivosoja J, Salo H, Rautiainen T. Review of remote sensing technologies for precision agriculture. Precis Agric. 2018;19(5):900–26. https://doi.org/10.1007/s11119-018-9587-y

46. Pallottino F, Costa C, Figorilli S, Menesatti P. UAVs for precision agriculture: Data acquisition and analysis. Agron Res. 2020;18(S1):234–44.

47. Pingale R, Jadhav V, Mane M. Role of UAVs in Indian agriculture: Opportunities and challenges. Int J Agric Sci. 2021;13(2):112–17.

48. Raj R, Kumar A, Sharma A. Drone applications in precision farming: Emerging trends. J Agric Technol. 2021;17(3):45–54.

49. Callon M, Courtial JP, Laville F. Co-word analysis as a tool for describing the network of interactions between basic and technological research: The case of polymer chemsitry. Scientometrics. 1991;22:155–205. https://doi.org/10.1007/BF02019280

50. Zahawi RA. Restoration of tropical forests: The potential of forest restoration programs in Latin America. Biol Conserv. 2015;182:23-34. https://doi.org/10.1016/j.biocon.2015.03.031

51. Huuskonen J. Evaluation of the effects of climate change on farm yields using remote sensing data. Comput Electron Agric. 2018;155:23-31. https://doi.org/10.1016/j.compag.2018.08.039

52. Jakob S. Remote sensing technology for precision agriculture. Remote Sens. 2017;9(1):88. https://doi.org/10.3390/rs9010088

53. Gnädinger F. Evaluation of remote sensing data for the assessment of vegetation health. Remote Sens. 2017;9(6):544. https://doi.org/10.3390/rs9060544

54. Latif G. The impact of remote sensing on environmental monitoring. Plants. 2022;11(17):2230. https://doi.org/10.3390/plants11172230

55. Reedha R. Remote sensing-based methods for crop monitoring and early warning. Remote Sens. 2022;14(3):592. https://doi.org/10.3390/rs14030592

56. Almalki FA. A study on sustainability in agriculture and remote sensing technologies. Sustainability. 2021;13(11):5908. https://doi.org/10.3390/su13115908

57. Gallo I. Evaluation of advanced remote sensing methods in agriculture. Remote Sens. 2023;15(2):539. https://doi.org/10.3390/rs15020539

58. Mesas-Carrascosa FJ. Remote sensing applications for soil health monitoring. Remote Sens. 2015;7(10):12793. https://doi.org/10.3390/rs71012793

59. Näsi R. Remote sensing techniques for environmental monitoring in agriculture. Remote Sens. 2018;10(7):1082. https://doi.org/10.3390/rs10071082

60. Alkhammash R. Bibliometric, network and thematic mapping analyses of metaphor and discourse in COVID-19 publications from 2020 to 2022. Front Psychol. 2023;13:1062943. https://doi.org/10.3389/fpsyg.2022.1062943

61. Murphy KR, Cleveland JN. Understanding performance appraisal: Social, organizational and goal-based perspectives. Sage Publications; 1995.

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.