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IoT Sensors and Applications in Agricultural Environments: Systematic Mapping

Sensores y aplicaciones de IoT en entornos agrícolas: mapeo sistemático

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Gardyn Olivera Ruiz
https://orcid.org/0000-0002-7200-6124
gardyn.olivera@unas.edu.pe
Universidad Nacional Agraria de la Selva. Tingo María, Peru

Giovanni Kuennen Perez Espinoza
https://orcid.org/0000-0002-4702-2413
giovanni.perez@unas.edu.pe
Universidad Nacional Agraria de la Selva. Tingo María, Peru

Abstract

This research systematically mapped the scientific literature on IoT sensors and applications in agriculture, aiming to identify the main lines of development, their benefits, and barriers to adoption. The Petersen and Kitchenham methodology was applied, using the PICOC framework to design the search in databases such as Scopus, IEEE Xplore, Taylor & Francis, and Sage Journals, considering original studies published between 2019 and 2024. From 1,862 initial records, 59 articles were selected after applying inclusion criteria related to technical description, analysis of advantages and limitations, and impact on sustainability. The bibliometric analysis showed a steady growth in publications, with Asia and Europe as the main focuses. The thematic synthesis revealed that smart irrigation systems account for 28% of contributions, followed by crop monitoring (17%) and early warning systems (10%). In contrast, areas such as smart fertilization and biodiversity conservation are little explored. Studies report significant improvements in water and energy efficiency, and a reduction in the environmental footprint. However, technical limitations persist, such as limited battery life, frequent calibrations, and protocol heterogeneity, in addition to limited socioeconomic evaluation. In conclusion, although IoT has great potential for more sustainable and resilient agriculture, its large-scale impact requires advances in energy autonomy, communications standardization, and cost-benefit studies to facilitate its adoption in small rural farms.

Keywords: precision agriculture, sustainable development, sensors.

Resumen

La presente investigación realizó un mapeo sistemático de la literatura científica sobre sensores y aplicaciones de IoT en la agricultura, con el objetivo de identificar las principales líneas de desarrollo, sus beneficios y las barreras para su adopción. Se aplicó la metodología de Petersen y Kitchenham, utilizando el marco PICOC para diseñar la búsqueda en bases de datos como Scopus, IEEE Xplore, Taylor & Francis y Sage Journals, considerando estudios originales publicados entre 2019 y 2024. De 1,862 registros iniciales, se seleccionaron 59 artículos tras aplicar criterios de inclusión relacionados con descripción técnica, análisis de ventajas y limitaciones, e impacto en sostenibilidad. El análisis bibliométrico mostró un crecimiento constante en las publicaciones, con Asia y Europa como principales focos. La síntesis temática reveló que los sistemas de riego inteligente concentran el 28 % de las contribuciones, seguidos por el monitoreo de cultivos (17 %) y los sistemas de alerta temprana (10 %). En contraste, áreas como fertilización inteligente y conservación de la biodiversidad están poco exploradas. Los estudios reportan mejoras significativas en eficiencia hídrica y energética, y reducción de la huella ambiental. Sin embargo, persisten limitaciones técnicas como la vida útil limitada de baterías, calibraciones frecuentes y heterogeneidad de protocolos, además de escasa evaluación socioeconómica. En conclusión, aunque el IoT tiene un gran potencial para una agricultura más sostenible y resiliente, su impacto a gran escala requiere avances en autonomía energética, estandarización de comunicaciones y estudios costo-beneficio que faciliten su adopción en pequeñas explotaciones rurales.

Palabras clave: agricultura de precisión, desarrollo sostenible, sensores.

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Introduction

Contemporary agriculture faces significant challenges, such as climate change, resource scarcity, and the continuous increase in food demand (FAO, 2020). In this context, the Internet of Things (IoT) emerges as a fundamental tool for enhancing the efficiency and sustainability of the sector. Through sensors, intelligent algorithms, and digital architectures, it is possible to optimize the use of water, energy, and fertilizers, thereby increasing productivity and reducing environmental impact (Baljon, 2024; Kumar et al., 2024). Technologies such as smart irrigation have already demonstrated positive results, especially in arid regions (Florea et al., 2024).

However, the implementation of IoT in agriculture faces various barriers, including limited connectivity, high initial costs, and a lack of adequate technical training (Lavanya & Muthu Mayil, 2019). Although innovations like digital twins (Mummaneni et al., 2024) and agricultural drones (Holtorf et al., 2023) show great potential, their adoption remains constrained. Therefore, it is essential to conduct a systematic analysis to identify the most relevant technologies, as well as their limitations and future opportunities.

In this context, the present study conducts a systematic mapping of the scientific literature on IoT in agriculture, aiming to identify the most commonly used types of sensors and applications, evaluate their benefits and limitations, and analyze their impact on sustainability. Methodologies employed include those proposed by Petersen et al. (2015), Kitchenham & Charters (2007), and the PICOC framework (Frandsen et al., 2020), analyzing 59 studies selected from an initial total of 1,862 publications.

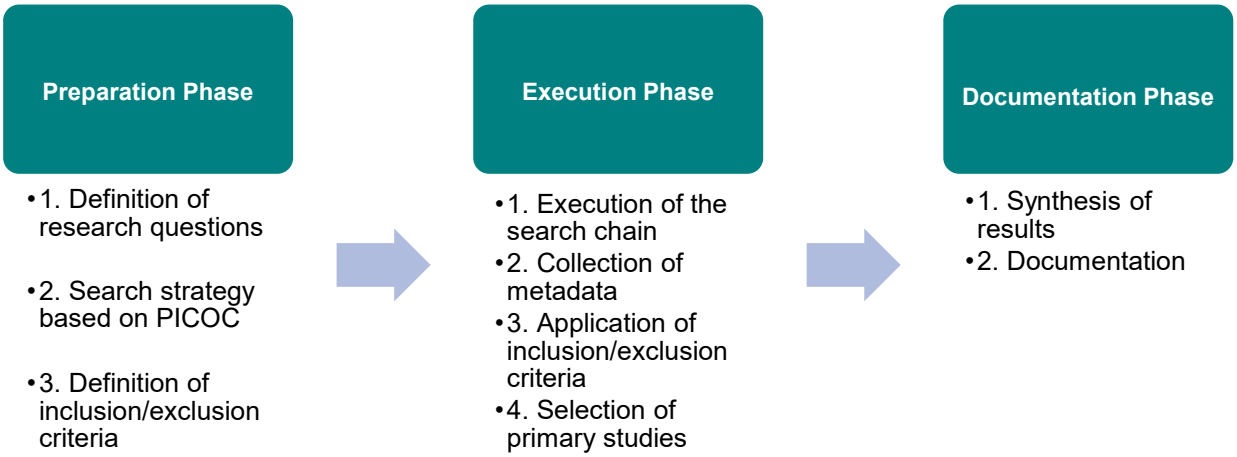
The results highlight the potential of smart irrigation, the emerging use of digital twins, and the increasing adoption of drones and autonomous vehicles. This work provides a comprehensive overview of the current state of IoT in agriculture and seeks to contribute to its effective and sustainable adoption, particularly in diverse and challenging contexts.

Methodology

The systematic mapping conducted in this research followed a structured approach based on the methodologies proposed by Petersen et al. (2015) and Kitchenham & Charters (2007).

Figure 1

Research methodology



A. Preparation phase

The purpose of this study was to conduct a systematic mapping that identifies and evaluates the most relevant studies on the use of sensors and IoT applications in agriculture. To this end, the main technologies, types of sensors employed, their advantages and limitations, as well as their contribution to the sustainability of the agricultural sector were analyzed.

Research questions

Four bibliometric questions were formulated to guide the analysis of scientific production (see Table 1).

Table 1

Bibliometric questions

ID	Bibliometric questions
BQ1	What is the trend and evolution of research on sensors and IoT applications in agriculture?
BQ3	Who are the main authors conducting research on sensors and IoT applications in agriculture?
BQ4	What are the most influential works in the research on sensors and IoT applications in agriculture?

Additionally, five research questions were posed to guide this systematic mapping (Table 2).

Table 2

Research questions

No.	Research questions
RQ1	What are the main types of sensors and IoT applications used in agriculture?
RQ2	What are the advantages and limitations of each type of sensor and IoT application identified?
RQ3	What is the frequency of use and relevance of these sensors and IoT applications in agricultural studies and cases?
RQ4	What is the impact of sensors and IoT applications on the sustainability of agricultural systems?
RQ5	What research methods are used in studies on sensors and IoT applications in agriculture?

B. Search strategy

To carry out the systematic mapping on the use of IoT technologies and sensors in agriculture, key repositories such as Scopus, IEEE Xplore, Taylor & Francis, and Sage Journals were selected due to their extensive relevance and coverage in specialized scientific literature. The research was guided by the PICOC framework (Population, Intervention, Comparison, Outcomes, and Context), which allowed for a clear definition of essential elements and the construction of robust and precise search chains (Frandsen et al., 2020). This strategy facilitated the identification of relevant studies, ensuring a thorough and structured review of the current state of knowledge in the field.

Table 3

Search terms based on the PICOC framework

Element	Search terms
Population	*agriculture OR farming*
Intervention	*sensor AND ("Internet of Things" OR IoT OR "IoT technology" OR "IoT applications")*
Comparison	*N/A*
Outcomes	*impact OR efficiency OR productivity OR sustainability*
Context	*"case studies" OR research OR analysis NOT review NOT urban*

C. Inclusion and exclusion criteria

Table 4 presents the inclusion (CI) and exclusion (CE) criteria used in the systematic mapping.

Table 4

Inclusion and exclusion criteria

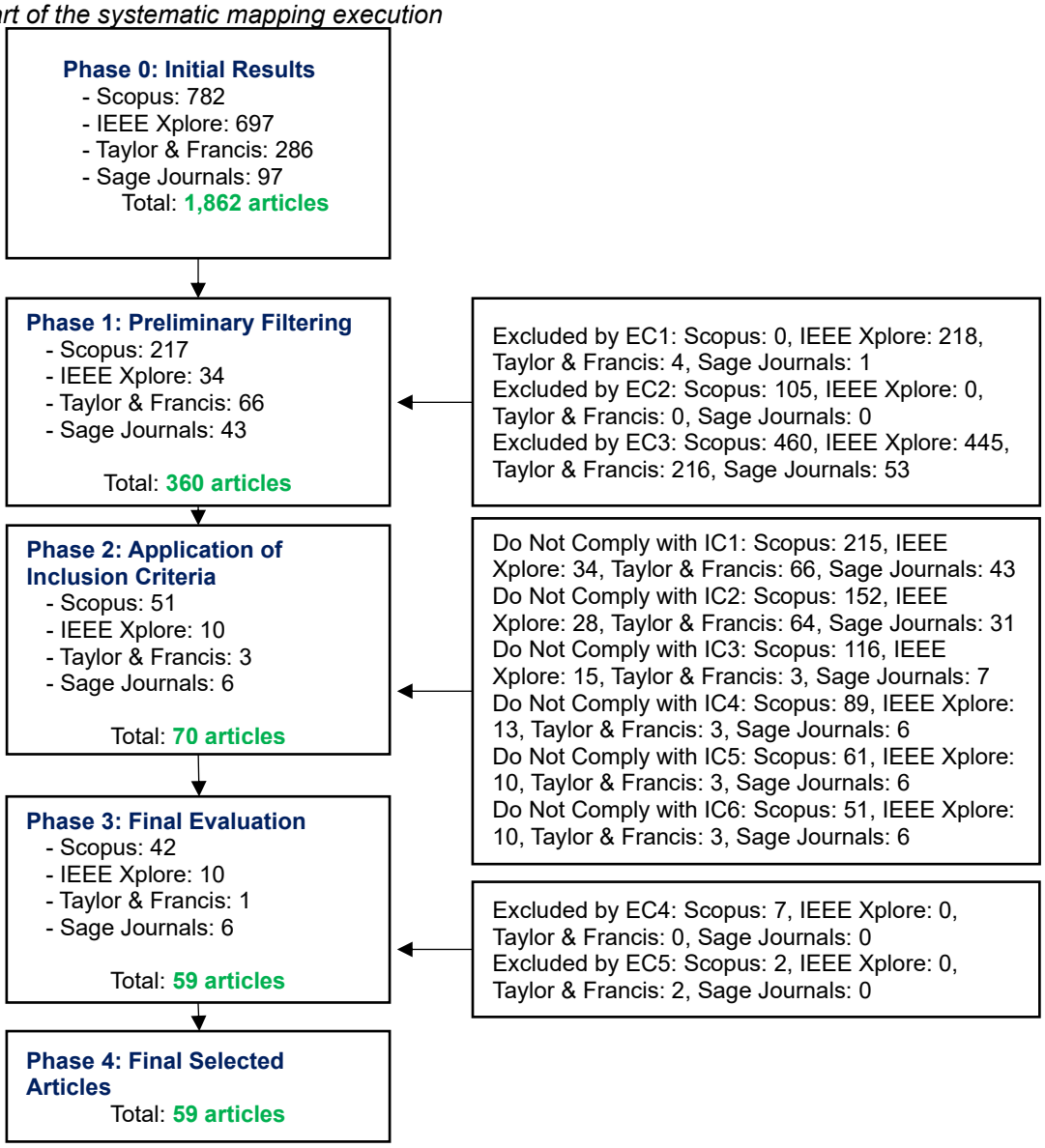
Type	ID	Criterion
IC	IC1	Studies published in English between 2019 and 2024.
	IC2	Research originating from primary information sources (original and empirical).
	IC3	Studies focused on the use of sensors and IoT applications in agricultural crops.
	IC4	Research addressing the advantages and limitations of IoT technologies.
	IC5	Studies that include specific technical details about sensors and their IoT applications.
	IC6	Studies considering the impact of IoT technologies on agricultural sustainability.
EC	EC1	Elimination of duplicate articles.
	EC2	Exclusion of book chapters, editorials, errata, retracted articles, and systematic reviews.
	EC3	Exclusion of studies that were not open access.
	EC4	Removal of articles with broken links, incomplete texts, or retracted content.
	EC5	Exclusion of studies that did not clearly address the research questions.

D. Execution phase

The selection process conducted in this systematic mapping is presented in Figure 2. In the first stage, 1,862 articles were identified in the selected databases (Scopus, IEEE Xplore, Taylor & Francis, and Sage Journals). Subsequently, these documents underwent thorough filtering in multiple phases, applying inclusion and exclusion criteria, until a total of 59 relevant studies were obtained. The complete traceability of this process is documented in a spreadsheet, which can be accessed via the following link: https://docs.google.com/spreadsheets/d/1ejnNMM0yBQXCCuNk9icvUcxypRJ6DdXJ/edit?usp=sharing&ouid=100997038000658880122&rtpof=true&sd=true

Figure 2

Flowchart of the systematic mapping execution



Results

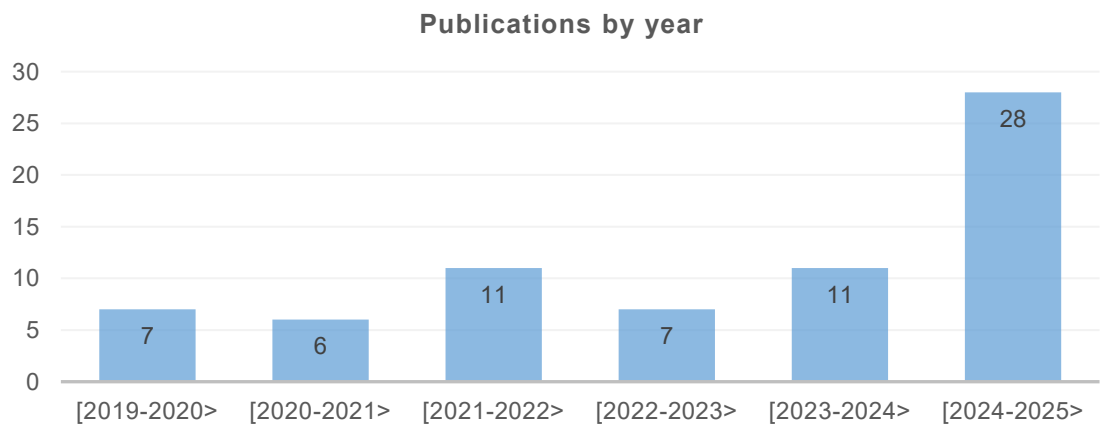
This section corresponds to the documentation phase, where the main findings obtained are recorded and analyzed, addressing the research questions proposed during the planning stage.

BQ1: What is the trend and evolution of research on IoT-based energy management systems?

Temporal evolution

The evolution of research during the selected period for mapping is presented in Figure 3.

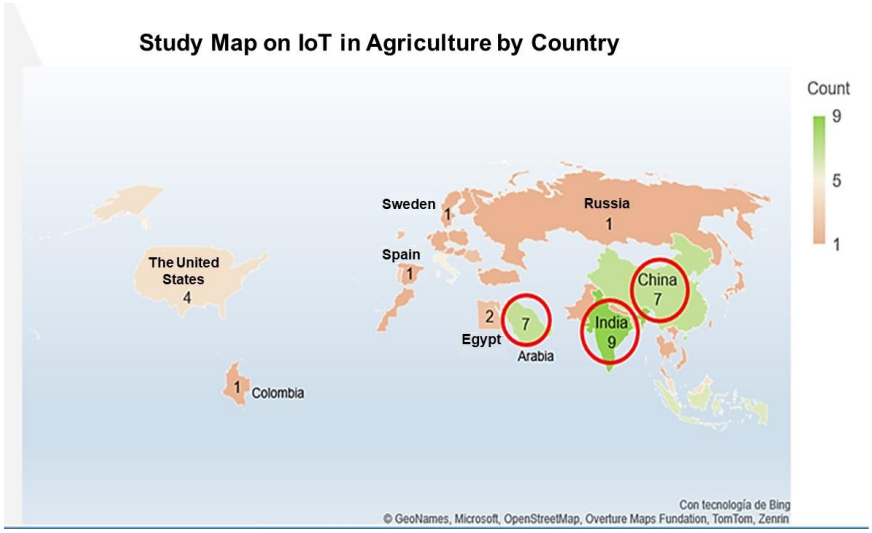
Figure 3
Temporal evolution



Geographic trend

The geographic distribution of research on IoT in agriculture is presented in the following figure.

Figure 4
Geographic trend



BQ2: Who are the main authors conducting research on sensors and IoT applications in agriculture?

Table 5 presents the most prominent authors in research on sensors and IoT applied to agriculture. These researchers have made significant contributions in areas such as precision agriculture, advanced crop monitoring, and the development of specialized IoT networks. Their contributions are supported by relevant academic indicators, including h-index, citation counts, and publication numbers, which reflect their influence and leadership in the field.

Table 5
Key authors focused on IoT-based energy management systems

Author	ORCID	Publications	Citations	h-index
Ahmad Almogren	0000-0002-8253-9709	282	8701	51

Ikram Ud Din	0000-0001-8896-547X	127	4664	39
Khalid Haseeb	0000-0001-6657-9308	83	2256	26
Pedro Sebastião	0000-0001-7729-4033	110	1016	18

BQ4: What are the most influential works in research on sensors and IoT applications in agriculture?

Table 6 presents the five most influential works in research on sensors and IoT applications in agriculture, highlighting their impact through citation counts and contributions in key areas such as sustainability, smart monitoring, and energy efficiency.

Table 6

Most influential works in research on sensors and IoT applications in agriculture

Title	Times Cited	Reference
An energy efficient and secure IoT-based WSN framework: An application to smart agriculture	192	(Haseeb et al., 2020)
Advanced UAV–WSN system for intelligent monitoring in precision agriculture	162	(Popescu et al., 2020)
Machine learning-based fog computing for early lameness detection in dairy cattle	93	(Taneja et al., 2020)
Energy-Efficient Edge-Fog-Cloud Architecture for IoT-Based Smart Agriculture Environment	65	(Alharbi & Aldossary, 2021)
Lora communications as an enabler for internet of drones towards large-scale livestock monitoring	62	(Behjati et al., 2021)

RQ1: What are the main types of IoT applications used in agriculture?

The main types of IoT applications used in agriculture, classified according to their focus, are presented in Table 7.

Table 7

Classification of studies by type of focus

Category	References
Smart Irrigation Systems	(Kumar et al., 2024), (Baljon, 2024), (Ibn Dahou Idrissi et al., 2024), (Florea et al., 2024), (Levin, 2024), (Arafa et al., 2024), (Kaur et al., 2024), (Dong et al., 2024), (Abdelmoneim et al., 2024), (Pham et al., 2021),(Glória et al., 2021), (Ullah et al., 2021), (Mohammed et al., 2021),(Alharbi & Aldossary, 2021), (Munaganuri & Rao, 2024), (Jia et al., 2019)
Crop Growth Monitoring	(Lavanya & Muthu Mayil, 2019), (Corbari et al., 2022), (Effah et al., 2024), (Priya et al., 2023), (Yin et al., 2023), (Arunachalam & Andreasson, 2022), (Jadhav et al., 2024), (Pineda-Castro et al., 2024), (Ting & Chan, 2024), (Alghazzawi et al., 2021)
Pest and Disease Control	(Mummaneni et al., 2024), (Mishra et al., 2023)
Drones for Precision Agriculture	(Holtorf et al., 2023), (Ammad Uddin et al., 2019), (Behjati et al., 2021), (Popescu et al., 2020), (Chittoor et al., 2023), (Chittoor et al., 2023), (Tiurlikova et al., 2019), (Liang & Juang, 2022)
Smart Harvest Storage Management	(Pérez-Pons et al., 2021)
Soil Health Monitoring	(Taparci et al., 2024), (Irwanto et al., 2024), (Ayu Nuning Farida Afiatna & Muflihah, 2024), (Prasad et al., 2023), (Postolache et al., 2023), (Nieman et al., 2024)

Nutrient Monitoring and Smart Fertilization	(Dash & Kumar, 2024), (Setyawan et al., 2024), (Islam et al., 2023b)
Monitoring and Early Warning Systems	(Yau et al., 2025), (Zito et al., 2024), (Sajak et al., 2024), (Satra et al., 2024), (Wibisono & Jayadi, 2024), (Putri et al., 2024), (Abid et al., 2024), (Kuang et al., 2020), (Taneja et al., 2020), (Armiento et al., 2023), (Haseeb et al., 2020), (Zhang & Liu, 2019)
Autonomous Vehicles for Agriculture	(Ram et al., 2020)

RQ2: What are the advantages and limitations of each type of sensor and IoT application identified?

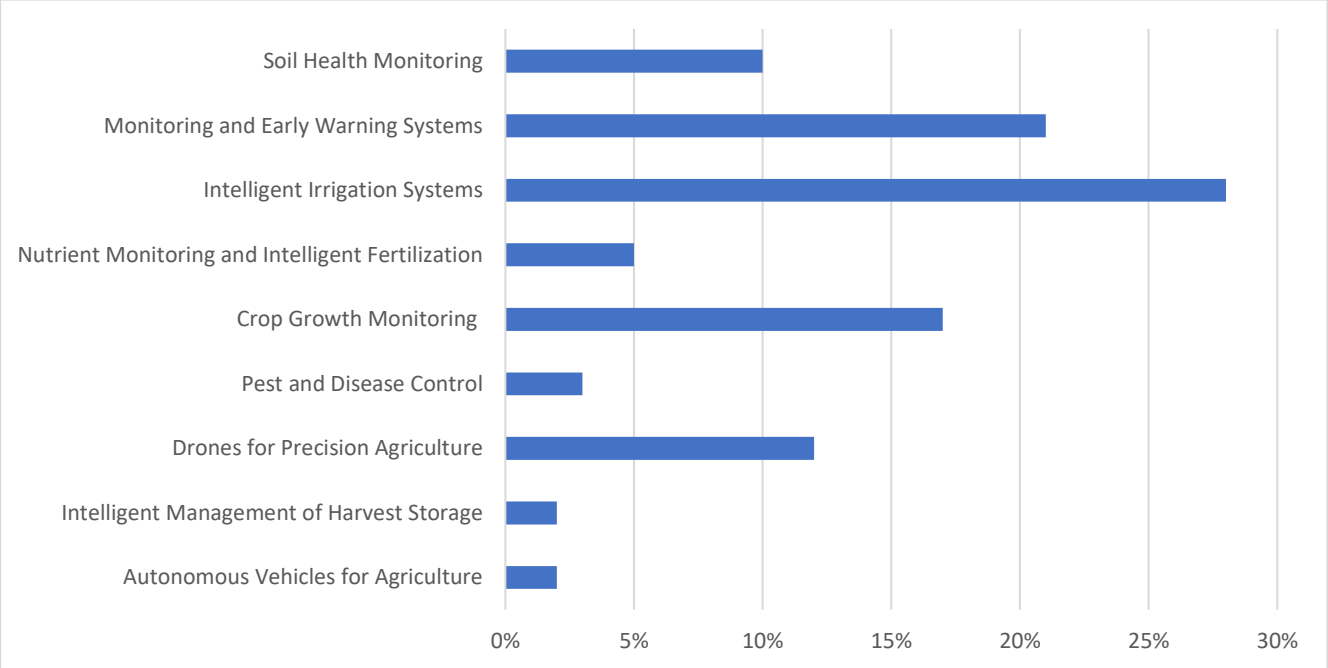
A detailed analysis of the advantages and limitations of sensors and IoT applications in agriculture was conducted using the Malta Cross tool. This study identified key sensors, such as soil moisture and environmental temperature sensors, which are essential for efficient water management, irrigation optimization, and climate monitoring. Among the main advantages are the efficient use of resources and real-time monitoring capabilities. However, significant limitations were also noted, such as battery dependency, the need for frequent calibrations, and sensitivity to various environmental conditions. Consequently, the urgency to innovate in aspects related to design, connectivity, and energy management is emphasized to overcome these challenges. Complete details of the analysis are available in: Análisis de la Cruz de Malta para IoT en Agricultura.

RQ3: What is the frequency of use and relevance of these sensors and IoT applications in agricultural studies?

Figure 5 shows the frequency of use of IoT applications in agricultural studies grouped by focus.

Figure 5

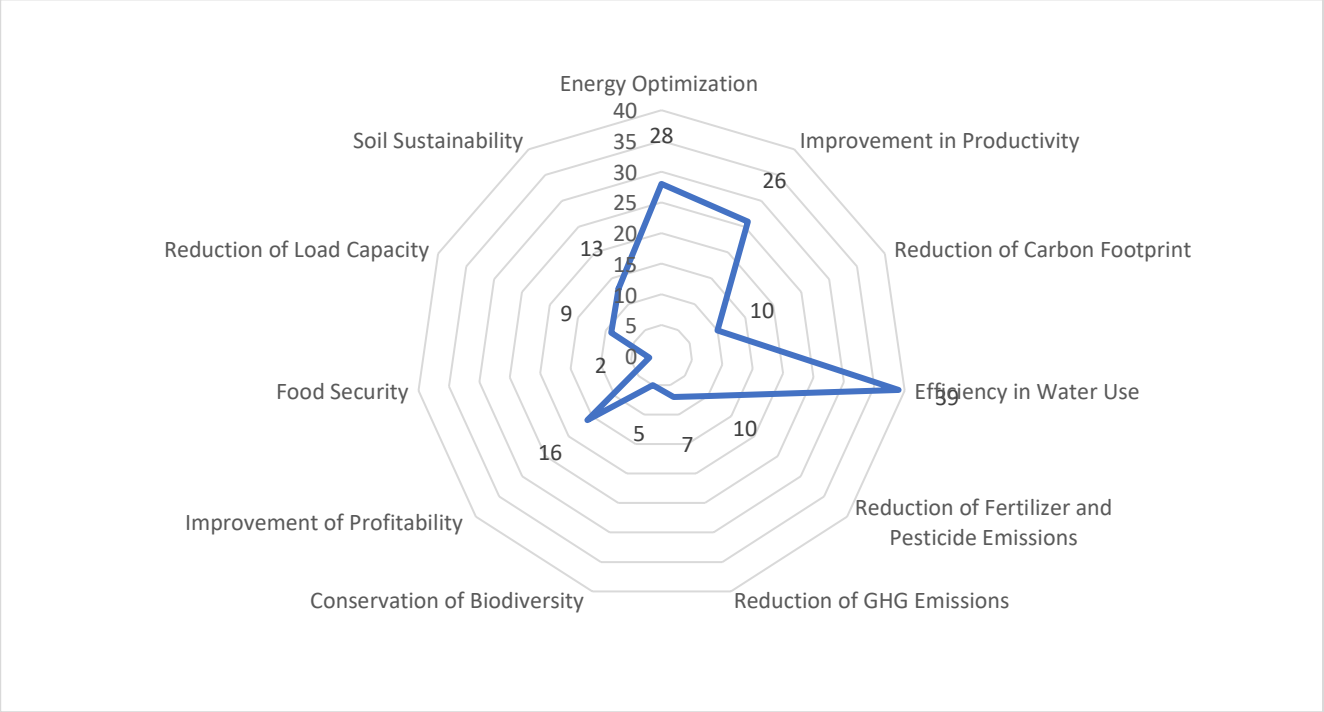
Percentage frequency grouped by IoT application focus



RQ4: What is the impact of sensors and IoT applications on the sustainability of agricultural systems?

The impact of sensors and IoT applications on agricultural sustainability is presented in Figure 6.

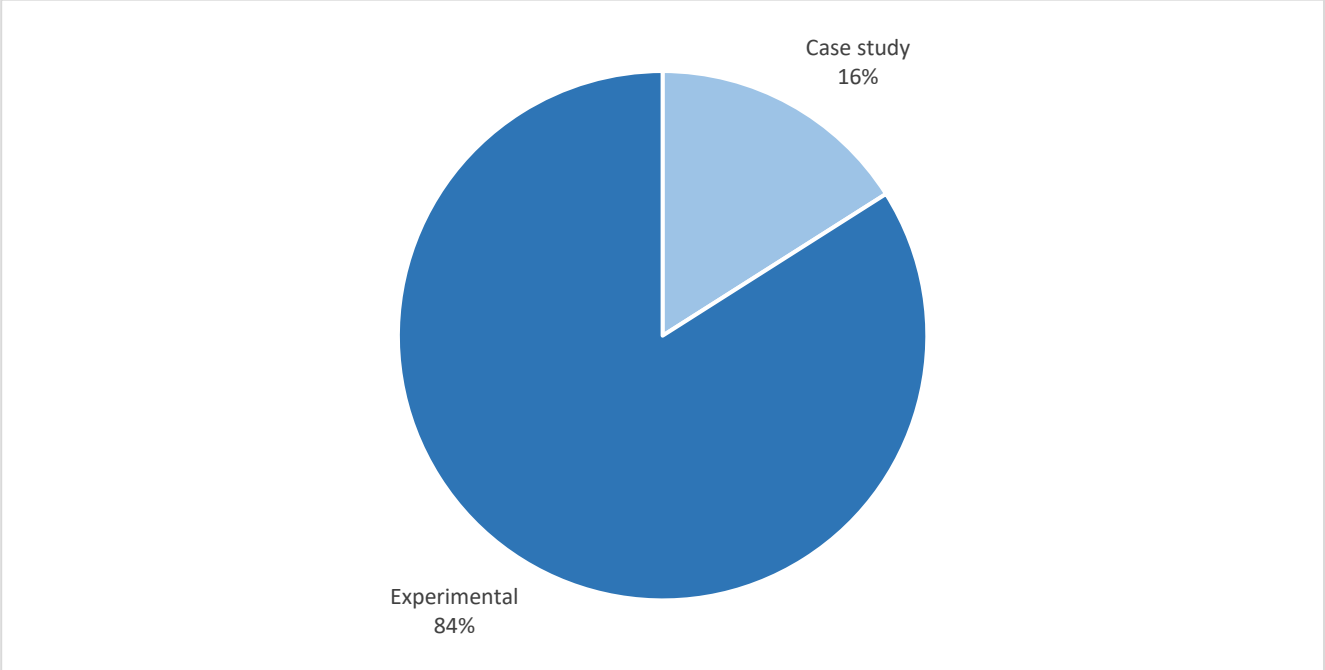
Figure 6
References by impact on sustainability



RQ5: What are the main research methods used in studies on sensors and IoT applications in agriculture?

The percentage of research methods used in studies on sensors and IoT applications in agriculture is presented in Figure 7.

Figure 7
Distribution of studies on sensors and IoT applications in agriculture by focus



Discussion

The analysis reveals a research landscape clearly dominated by smart irrigation, which accounts for 28% of the studies and reports reductions in water consumption exceeding 25% in controlled nurseries, as demonstrated by Florea et al. (2024). In contrast, smart fertilization represents only 5%, highlighting an imbalanced thematic agenda, as documented by Islam et al. (2023). This bias is further reinforced by the geographic concentration of studies in countries such as India and China, where state digitalization programs facilitate the adoption of edge-fog-cloud architectures and low-cost sensors, as detailed by Kumar et al. (2024). Conversely, the dissemination of these technologies in Latin America is limited due to deficiencies in connectivity and funding, a situation described by Pérez-Pons et al. (2021).

From a technical perspective, energy autonomy continues to be the primary challenge. For example, economical tensiometers exhibit calibration deviations exceeding 5% after 90 days of continuous operation, according to Arafa et al. (2024). Furthermore, the coexistence of heterogeneous wireless protocols generates congestion and data loss in LoRa-Wi-Fi networks, as reported by Behjati et al. (2021). However, NB-IoT platforms applied to irrigation have managed to reduce electricity consumption by up to 21%, according to Ullah et al. (2021).

Nevertheless, only 16% of studies validate their prototypes under real field conditions, making it difficult to estimate the return on investment for small producers. Effah et al. (2024) emphasize this deficiency and the need for rigorous cost-benefit evaluations. Collectively, these findings confirm the potential of IoT to enhance agricultural efficiency but also highlight the urgency of developing self-sustaining nodes, standardizing open protocols, and expanding research into socioeconomic dimensions and underexplored themes to achieve equitable and sustainable adoption.

Conclusions

The analysis of 59 studies on IoT in agriculture confirms significant advancements in resource optimization, crop monitoring, and energy efficiency, with Asia—especially India, Saudi Arabia, and China—leading the development. Researchers such as Ahmad Almogren, Ikram Ud Din, and Khalid Haseeb stand out as key figures in IoT networks and precision agriculture. However, significant gaps in infrastructure and funding persist in regions such as Latin America and Europe, limiting equitable adoption and underscoring the need to classify IoT applications to identify research gaps.

The mapping reveals three predominant thematic axes: smart irrigation (28%), crop monitoring (17%), and soil health or pest control. In contrast, emerging areas such as smart fertilization (5%) and other disruptive technologies based on machine learning and digital twins remain underexplored. Additionally, the use of drones, autonomous vehicles, and early warning systems extends the reach of IoT into post-harvest and risk management, although their implementation still faces practical challenges.

Among the main technical barriers are the fixed location of sensors, limited battery life, sensitivity to environmental conditions, and the need for frequent recalibrations. Overcoming these obstacles requires the development of energy-autonomous nodes, more robust designs, and adaptive solutions. Moreover, the current focus on water and energy efficiency contrasts with the lesser attention to soil sustainability and food security, necessitating a more balanced approach.

Finally, the predominance of experimental studies (84%) compared to field cases (16%) complicates the estimation of real benefits and the return on investment for small producers. Thus, balancing controlled validations with field pilots is essential for replicating and scaling IoT solutions that promote truly sustainable and resilient agriculture.

References

Abdelmoneim, A. A., Khadra, R., Elkamouh, A., Derardja, B., & Dragonetti, G. (2024). Towards affordable precision irrigation: An experimental comparison of weather-based and soil water potential-based irrigation using low-cost IoT-tensiometers on drip irrigated lettuce. *Sustainability*, *16*(1), 306. https://doi.org/10.3390/su16010306

Abid, M. A., Amjad, M., Munir, K., Siddique, H. U. R., & Jurcut, A. D. (2024). IoT-based smart biofloc monitoring system for fish farming using machine learning. *IEEE Access*, *12*, 86333–86345. https://doi.org/10.1109/ACCESS.2024.3384263

Alghazzawi, D., Bamasaq, O., Bhatia, S., Kumar, A., Dadheech, P., & Albeshri, A. (2021). Congestion control in cognitive IoT-based WSN network for smart agriculture. *IEEE Access*, *9*, 151401–151420. https://doi.org/10.1109/ACCESS.2021.3124791

Alharbi, H. A., & Aldossary, M. (2021). Energy-efficient edge-fog-cloud architecture for IoT-based smart agriculture environment. *IEEE Access*, *9*, 110480–110492. https://doi.org/10.1109/ACCESS.2021.3101397

Alves, R., & Matos, P. (2023). A solution to prevent and minimize the consequences of accidents with farm tractors in the context of mountainous regions with low population density. *Sensors*, *23*(18), 7811. https://doi.org/10.3390/s23187811

Ammad Uddin, M., Ayaz, M., Aggoune, E. H. M., Mansour, A., & Le Jeune, D. (2019). Affordable broad agile farming system for rural and remote area. *IEEE Access*, *7*, 127098–127116. https://doi.org/10.1109/ACCESS.2019.2937881

Arafa, Y., El-Gindy, A. G. M., El-Shirbeny, M., Bourouah, M., Abd-ElGawad, A. M., Rashad, Y. M., Hafez, M., & Youssef, M. A. (2024). Improving the spatial deployment of the soil moisture sensors in smart irrigation systems using GIS. *Cogent Food and Agriculture*, *10*(1), 2361124. https://doi.org/10.1080/23311932.2024.2361124

Armiento, S., Meder, F., & Mazzolai, B. (2023). Device for simultaneous wind and raindrop energy harvesting operating on the surface of plant leaves. *IEEE Robotics and Automation Letters*, *8*(4), 2269–2276. https://doi.org/10.1109/LRA.2023.3250006

Arunachalam, A., & Andreasson, H. (2022). RaspberryPi-Arduino (RPA) powered smart mirrored and reconfigurable IoT facility for plant science research. *Internet Technology Letters*, *5*(1), e272. https://doi.org/10.1002/itl2.272

Ayu Nuning Farida Afiatna, F., & Muflihah, N. (2024). The monitoring system of soil pH factor using IoT-webserver-android and machine learning: A case study. *Int. J. Adv. Sci. Eng. Inf. Technol., 14*(1), 118–130. https://doi.org/10.18517/ijaseit.14.1.18745

Baljon, M. (2024). Revolutionizing Saudi Arabia's agriculture: The IoT transformation of water management. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *36*(1), 217–240. https://doi.org/10.37934/araset.36.1.217240

Behjati, M., Mohd Noh, A. B., Alobaidy, H. A. H., Zulkifley, M. A., Nordin, R., & Abdullah, N. F. (2021). LoRa communications as an enabler for internet of drones towards large-scale livestock monitoring in rural farms. *Sensors*, *21*(15), 5044. https://doi.org/10.3390/s21155044

Chittoor, P. K., Chokkalingam, B., Verma, R., & Mihet-Popa, L. (2023). An assessment of shortest prioritized path-based bidirectional wireless charging approach toward smart agriculture. *IEEE Access*, *11*, 123742–123755. https://doi.org/10.1109/ACCESS.2023.3329976

Corbari, C., Paciolla, N., Ben Charfi, I., Skokovic, D., Sobrino, J. A., & Woods, M. (2022). Citizen science supporting agricultural monitoring with hundreds of low-cost sensors in comparison to remote sensing data. *European Journal of Remote Sensing*, *55*(1), 388–408. https://doi.org/10.1080/22797254.2022.2084643

Dash, S. S., & Kumar, P. (2024). Farmers' toolkit: Deep learning in weed detection and precision crop & fertilizer recommendations. *BIO Web of Conferences*, *82*, 05012. https://doi.org/10.1051/bioconf/20248205012

Debangshi, U. (2021). Drone-applications in agriculture. https://doi.org/10.5281/zenodo.5554734

Dong, Y., Werling, B., Cao, Z., & Li, G. (2024). Implementation of an in-field IoT system for precision irrigation management. *Frontiers in Water*, *6*, 1353597. https://doi.org/10.3389/frwa.2024.1353597

Effah, E., Thiare, O., & Wyglinski, A. M. (2024). Hardware evaluation of cluster-based agricultural IoT network. *IEEE Access*, *12*, 33628–33651. https://doi.org/10.1109/ACCESS.2024.3370230

FAO. (s.f.). El futuro de la alimentación y la agricultura: Tendencias y desafíos. *Panorama General*. www.fao.org/faostat/es/#home

Florea, A., Popa, D. I., Morariu, D., Maniu, I., Berntzen, L., & Fiore, U. (2024). Digital farming based on a smart and user-friendly IoT irrigation system: A conifer nursery case study. *IET Cyber-Physical Systems: Theory and Applications*, *9*(2), 150–168. https://doi.org/10.1049/cps2.12054

Frandsen, T. F., Bruun Nielsen, M. F., Lindhardt, C. L., & Eriksen, M. B. (2020). Using the full PICO model as a search tool for systematic reviews resulted in lower recall for some PICO elements. *Journal of Clinical Epidemiology*, *127*, 69–75. https://doi.org/10.1016/j.jclinepi.2020.07.005

Glória, A., Cardoso, J., & Sebastião, P. (2021). Sustainable irrigation system for farming supported by machine learning and real-time sensor data. *Sensors*, *21*(9), 3079. https://doi.org/10.3390/s21093079

Haseeb, K., Din, I. U., Almogren, A., & Islam, N. (2020). An energy efficient and secure IoT-based WSN framework: An application to smart agriculture. *Sensors*, *20*(7), 2081. https://doi.org/10.3390/s20072081

Holtorf, L., Titov, I., Daschner, F., & Gerken, M. (2023). UAV-based wireless data collection from underground sensor nodes for precision agriculture. *AgriEngineering*, *5*(1), 338–354. https://doi.org/10.3390/agriengineering5010022

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Ibn Dahou Idrissi, A., Abouabdillah, A., Chikhaoui, M., & Bouabid, R. (2024). Low-cost IoT-based monitoring system for precision agriculture. *E3S Web of Conferences*, *492*, 01003. https://doi.org/10.1051/e3sconf/202449201003

Irwanto, F., Hasan, U., Lays, E. S., De La Croix, N. J., Mukanyiligira, D., Sibomana, L., & Ahmad, T. (2024). IoT and fuzzy logic integration for improved substrate environment management in mushroom cultivation. *Smart Agricultural Technology*, *7*, 100427. https://doi.org/10.1016/j.atech.2024.100427

Islam, M. R., Oliullah, K., Kabir, M. M., Alom, M., & Mridha, M. F. (2023a). Machine learning enabled IoT system for soil nutrients monitoring and crop recommendation. *Journal of Agriculture and Food Research*, *14*, 100880. https://doi.org/10.1016/j.jafr.2023.100880

Islam, M. R., Oliullah, K., Kabir, M. M., Alom, M., & Mridha, M. F. (2023b). Machine learning enabled IoT system for soil nutrients monitoring and crop recommendation. *Journal of Agriculture and Food Research*, *14*, 100880. https://doi.org/10.1016/j.jafr.2023.100880

Jadhav, N., Rajnivas, B., Subapriya, V., Sivaramakrishnan, S., Premalatha, S., & Poongodi, P. (2024). Enhancing crop growth efficiency through IoT-enabled smart farming system. *EAI Endorsed Transactions on Internet of Things*, *10*. https://doi.org/10.4108/eetiot.4604

Jia, X., Huang, Y., Wang, Y., & Sun, D. (2019). Research on water and fertilizer irrigation system of tea plantation. *International Journal of Distributed Sensor Networks*, *15*(3). https://doi.org/10.1177/1550147719840182

Jimale, A. D., Abdullahi, M. O., Ahmed, Y. A., & Nageye, A. Y. (2023). Towards sustainable farming in Somalia: Integrating IoT for improved resource management. *SSRG International Journal of Electrical and Electronics Engineering*, *10*(9), 95–101. https://doi.org/10.14445/23488379/IJEEE-V10I9P109

Kaur, A., Bhatt, D. P., & Raja, L. (2024). Developing a hybrid irrigation system for smart agriculture using IoT sensors and machine learning in Sri Ganganagar, Rajasthan. *Journal of Sensors*, 2024, 6676907. https://doi.org/10.1155/2024/6676907

Kitchenham, B. & Charters, S. (2007) Guidelines for Performing Systematic Literature Reviews in Software Engineering, Technical Report EBSE 2007-001, Keele University and Durham University Joint Report. https://www.researchgate.net/publication/302924724_Guidelines_for_performing_Systematic_Literature_Reviews_in_Software_Engineering

Kuang, L., Shi, P., Hua, C., Chen, B., & Zhu, H. (2020). An enhanced extreme learning machine for dissolved oxygen prediction in wireless sensor networks. *IEEE Access*, *8*, 198730–198739. https://doi.org/10.1109/ACCESS.2020.3033455

Kumar, G. K., Bangare, M. L., Bangare, P. M., Kumar, C. R., Raj, R., Arias-Gonzáles, J. L., Omarov, B., & Mia, M. S. (2024). Internet of things sensors and support vector machine integrated intelligent irrigation system for agriculture industry. *Discover Sustainability*, *5*(1), 6. https://doi.org/10.1007/s43621-024-00179-5

Lavanya, P., & Muthu Mayil, K. (2019). IoT-based wireless sensors for agriculture monitoring. *International Journal of Recent Technology and Engineering*, *8*(2), 177–181. https://doi.org/10.35940/ijrte.B1033.0782S419

Levin, S. (2024). Intelligent monitoring and management in the agro-industrial complex. *E3S Web of Conferences*, *539*, 02016. https://doi.org/10.1051/e3sconf/202453902016

Liang, W. Y., & Juang, J. G. (2022). Application of image identification to UAV control for cage culture. *Science Progress*, *105*(4). https://doi.org/10.1177/00368504221135450

Mishra, S., Volety, D. R., Bohra, N., Alfarhood, S., & Safran, M. (2023). A smart and sustainable framework for millet crop monitoring equipped with disease detection using enhanced predictive intelligence. *Alexandria Engineering Journal*, *83*, 298–306. https://doi.org/10.1016/j.aej.2023.10.041

Mohammed, M., Riad, K., & Alqahtani, N. (2021). Efficient IoT-based control for a smart subsurface irrigation system to enhance irrigation management of date palm. *Sensors*, *21*(12), 3942. https://doi.org/10.3390/s21123942

Mummaneni, S., Sappa, T. S., & Katakam, V. G. D. (2024). Enhancing crop health through digital twin for disease monitoring and nutrient balance. *Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Srodowiska*, *14*(1), 57–62. https://doi.org/10.35784/iapgos.5626

Munaganuri, R. K., & Rao, Y. N. (2024). PAMICRM: Improving precision agriculture through multimodal image analysis for crop water requirement estimation using multidomain remote sensing data samples. *IEEE Access*, *12*, 52815–52836. https://doi.org/10.1109/ACCESS.2024.3386552

Nieman, B., Johnson, C. S., Pearce, M., Marcrum, T., Thorne, M. C., Ashby, C., & Van Neste, C. W. (2024). Through the soil long range wireless power transfer for agricultural IoT networks. *IEEE Transactions on Industrial Electronics*, *71*(2), 2090–2099. https://doi.org/10.1109/TIE.2023.3250743

Pérez-Pons, M. E., Plaza-Hernández, M., Alonso, R. S., Parra-Domínguez, J., & Prieto, J. (2021). Increasing profitability and monitoring environmental performance: A case study in the agri-food industry through an edge-IoT platform. *Sustainability*, *13*(1), 1–16. https://doi.org/10.3390/su13010283

Petersen, K., Vakkalanka, S., & Kuzniarz, L. (2015). Guidelines for conducting systematic mapping studies in software engineering: An update. *Information and Software Technology*, *64*, 1–18. https://doi.org/10.1016/J.INFSOF.2015.03.007

Pham, V. B., Diep, T. T., Fock, K., & Nguyen, T. S. (2021). Using the Internet of Things to promote alternate wetting and drying irrigation for rice in Vietnam's Mekong Delta. *Agronomy for Sustainable Development*, *41*(3), 43. https://doi.org/10.1007/s13593-021-00705-z

Pineda-Castro, D., Diaz, H., Soto, J., & Urban, M. O. (2024). LysipheN: A gravimetric IoT device for near real-time high-frequency crop phenotyping: A case study on common beans. *Plant Methods*, *20*(1), 39. https://doi.org/10.1186/s13007-024-01170-x

Popescu, D., Stoican, F., Stamatescu, G., Ichim, L., & Dragana, C. (2020). Advanced UAV–WSN system for intelligent monitoring in precision agriculture. *Sensors*, *20*(3), 817. https://doi.org/10.3390/s20030817

Postolache, S., Sebastião, P., Viegas, V., Postolache, O., & Cercas, F. (2023). IoT-based systems for soil nutrients assessment in horticulture. *Sensors*, *23*(1), 403. https://doi.org/10.3390/s23010403

Prasad, R., Tiwari, R., & Srivastava, A. K. (2023). Internet of Things-based fuzzy logic controller for smart soil health monitoring: A case study of semi-arid regions of India. *Engineering Proceedings*, *58*(1), 85. https://doi.org/10.3390/ecsa-10-16208

Priya, G. L., Baskar, C., Deshmane, S. S., Adithya, C., & Das, S. (2023). Revolutionizing holy-basil cultivation with AI-enabled hydroponics system. *IEEE Access*, *11*, 82624–82639. https://doi.org/10.1109/ACCESS.2023.3300912

Putri, R. E., Lestari, N. U., Ifmalinda, Arlius, F., Putri, I., & Hasan, A. (2024). Monitoring and controlling system of smart mini greenhouse based on Internet of Things (IoT) for spinach plant (Amaranthus sp.). *International Journal on Advanced Science, Engineering and Information Technology*, *14*(1), 131–136. https://doi.org/10.18517/ijaseit.14.1.18408

Ram, C. R. S., Ravimaran, S., Krishnan, R. S., Julie, E. G., Robinson, Y. H., Kumar, R., Son, L. H., Thong, P. H., Thanh, N. Q., & Ismail, M. (2020). Internet of green things with autonomous wireless wheel robots against greenhouses and farms. *International Journal of Distributed Sensor Networks*, *16*(6). https://doi.org/10.1177/1550147720923477

Sajak, A. A. B., Ahmad, M. N. I., & Dao, H. (2024). Green IoT based on tropical weather: The impact of energy harvesting in wireless sensor network. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *40*(1), 35–44. https://doi.org/10.37934/araset.40.1.3544

Satra, R., Hadi, M. S., Sujito, Febryan, Fattah, M. H., & Busaeri, S. R. (2024). IoAT: Internet of aquaculture things for monitoring water temperature in tiger shrimp ponds with DS18B20 sensors and WeMos D1 R2. *Journal of Robotics and Control (JRC)*, *5*(1), 62–71. https://doi.org/10.18196/jrc.v5i1.18470

Setyawan, D. Y., Warsito, Marjunus, R., & Sumaryo. (2024). A novel controlling system for smart farming-based Internet of Things (IoT). *International Journal of Advanced Computer Science and Applications*, *15*(5), 630–641. https://doi.org/10.14569/IJACSA.2024.0150563

Sharma, A., Jain, A., Gupta, P., & Chowdary, V. (2021). Machine learning applications for precision agriculture: A comprehensive review. *IEEE Access*, *9*, 4843–4873. https://doi.org/10.1109/ACCESS.2020.3048415

Tagarakis, A. C., Kateris, D., Berruto, R., & Bochtis, D. (2021). Low-cost wireless sensing system for precision agriculture applications in orchards. *Applied Sciences*, *11*(13), 5858. https://doi.org/10.3390/app11135858

Taneja, M., Byabazaire, J., Jalodia, N., Davy, A., Olariu, C., & Malone, P. (2020). Machine learning based fog computing assisted data-driven approach for early lameness detection in dairy cattle. *Computers and Electronics in Agriculture*, *171*, 105286. https://doi.org/10.1016/J.COMPAG.2020.105286

Taparci, E., Olcay, K., Akmandor, M. O., Kabakulak, B., Sarioglu, B., & Gokdel, Y. D. (2024). A mathematical programming approach for IoT-enabled, energy-efficient heterogeneous wireless sensor network design and implementation. *Sensors*, *24*(5), 1457. https://doi.org/10.3390/s24051457

Ting, Y. T., & Chan, K. Y. (2024). Optimising performances of LoRa based IoT enabled wireless sensor network for smart agriculture. *Journal of Agriculture and Food Research*, *16*, 101093. https://doi.org/10.1016/j.jafr.2024.101093

Tiurlikova, A., Stepanov, N., & Mikhaylov, K. (2019). Wireless power transfer from unmanned aerial vehicle to low-power wide area network nodes: Performance and business prospects for LoRaWAN. *International Journal of Distributed Sensor Networks*, *15*(11). https://doi.org/10.1177/1550147719888165

Ullah, R., Abbas, A. W., Ullah, M., Khan, R. U., Khan, I. U., Aslam, N., & Aljameel, S. S. (2021). EEWMP: An IoT-based energy-efficient water management platform for smart irrigation. *Scientific Programming*, 2021, 5536884. https://doi.org/10.1155/2021/5536884

Wibisono, A. B., & Jayadi, R. (2024). Experimental IoT system to maintain water quality in catfish pond. *International Journal of Advanced Computer Science and Applications*, *15*(3), 393–399. https://doi.org/10.14569/IJACSA.2024.0150340

Wu, Y., Yang, Z., & Liu, Y. (2023). Internet-of-things-based multiple-sensor monitoring system for soil information diagnosis using a smartphone. *Micromachines*, *14*(7), 1395. https://doi.org/10.3390/mi14071395

Yau, S. R., Jalani, J., Sadun, A. S., Rejab, S. M., & John, J. (2025). Development of an aquaponics farming technology system using Arduino based on Internet of Things. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *45*(2), 11–24. https://doi.org/10.37934/araset.45.2.1124

Yin, D., Wang, Y., & Huang, Y. (2023). Predicting soil moisture content of tea plantation using support vector machine optimized by arithmetic optimization algorithm. *Journal of Algorithms and Computational Technology*, *17*. https://doi.org/10.1177/17483026221151198

Zhang, C., & Liu, Z. (2019). Application of big data technology in agricultural Internet of Things. *International Journal of Distributed Sensor Networks*, *15*(10). https://doi.org/10.1177/1550147719881610

Zito, F., Giannoccaro, N. I., Serio, R., & Strazzella, S. (2024). Analysis and development of an IoT system for an agrivoltaics plant. *Technologies*, *12*(7), 106. https://doi.org/10.3390/technologies12070106