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Towards Agriculture 5.0: An IoT Framework for Precision Farming

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Abstract

The 2023 Global Hunger Index reports a serious hunger condition in most of the developing countries. In some contexts, the agricultural activities are being transformed by emerging digital technologies such as Internet of Things (IoT) in accordance with the requirements of Agriculture 5.0. The research is a systematic literature review (SLR) based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The SLR involves 34 peer-reviewed articles published in ACM digital library between 2020 and 2024. The study's findings demonstrate that precision technologies such as IoT can address the challenges hindering subsistence farmers from progressing towards agriculture 5.0, The results of the study provide subsistence farmers with guidelines for implementing precision technologies to improve decision making on crop selection, disease detection, yield prediction, nutrient requirements and application. The findings of this research have significant implications on policymakers, researchers, and agricultural stakeholders. The study provides evidence-based policy recommendations to policymakers with an interest in IoT. Furthermore, the study presents a conceptual framework to guide farmers and agribusiness stakeholders to select relevant precision technologies for improving agricultural activities and direct them towards agriculture 5.0.

Keywords
Internet of Things (IoT), Precision Farming, Crop and Sustainable Agriculture.

1. Introduction
Modern agriculture experienced major changes through the quick development of digital technology in recent decades. The Internet of Things along with its extensive adoption in smart agriculture operations allows this transformation to occur. The continuous integration of IoT technologies makes modern agricultural operations more efficient and sustainable while generating new possibilities for productivity increases. Through IoT technology integration into smart agriculture farmers and agribusinesses have revolutionized their methods of managing crops and managing irrigation distribution and pest management and resource planning. These technological systems provide continuous monitoring of environmental and operational parameters to detect perfect conditions for planting and harvesting and fertilizer or pesticide application thus improving production levels and cutting down resource losses (Patil et al. 2023; Rehman et al. 2022).

1.1 Research Questions
Main question:
How can the adoption of precision farming be increased?
Sub-questions
1. How do agribusinesses benefit from implementing IoT in their operations?

2. How are IoT technologies utilized in precision agriculture?
3. How is the adoption of IoT technologies hindered in smart agriculture?

2.Methodology

This study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al 2009). Following the PRISMA protocol in conducting the study ensured transparency and reproducibility in the search and selection process.

Search strategy:

An example of the search string used in the ACM database is as follows:
(("internet of things" OR "IoT”) AND ("precision farming" OR "precision agriculture" OR "smart farming" OR "smart agriculture”) AND ("crop*" OR “produce”) AND (“sustainable agriculture”)

Table 1. research protocol

Protocol element	Translation in research
Digital libraries	ACM, Springer and IEEE Xplore
Inclusion criteria	• Focus on the application of IoT technologies in the agricultural domain, including but not limited to precision farming, and environmental monitoring. • Published in peer-reviewed journals, conference proceedings, or reputable industry reports between 2020 and 2024. • Written in English language. • Providing empirical findings, case studies, or comprehensive reviews on the deployment and impact of IoT technologies in smart agriculture.
Exclusion criteria	• Focused solely on the technical aspects of IoT technology hardware or software without discussing their practical applications in agriculture. • Addressed the broader topic of precision agriculture or smart farming without a specific focus on IoT technologies. • Were published before January 2020 or after august 2024. • We’re not accessible in full-text format or were not written in the English language. • Presented only conceptual frameworks or theoretical models without empirical evidence or case studies. • We’re Comprehensive reviews and synthesis of existing literature

Screening process

The study selection process is summarized in the PRISMA flow diagram (Figure 1).

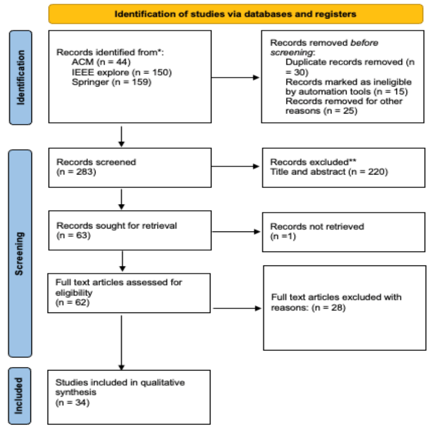

Figure 1. PRISMA flow diagram of the study selection process

Table 2. The 34 Studies included in the review

ID	Author	Country	Methodology	Framework	IoT technologies	Factors affecting the adoption of IoT	Application area
1	(Ahmareen, Potluri & Alabdouli 2024)	UAE	• Quantitative		• Sensors • Actuators	• Automation of agricultural tasks • Increased Agricultural Productivity and efficiency • High investment • Technical Expertise required for setup and maintenance • Coverage and connectivity	• Soil Monitoring • Environmental monitoring • Water management
2	(Bhattacharya & Pandey 2023)	India	• Quantitative		• Sensors • Actuators • Connectivity Protocols • Edge Computing • Data Analytics and Machine Learning • User Interfaces	• Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • High investment • Scalability • Data consistency and reliability • Infrastructure • Technical Expertise required for setup and maintenance	• Soil Monitoring • Nutrient monitoring • Environmental monitoring
3	(Chavakula, Mahamuni, Agrawal, Alla & Adhav 2024)	India			• Sensors • Actuators • Connectivity protocols • Cloud computing • Data analytics and machine learning • User interfaces	• Real-time monitoring and data driven decision-making • Automation of agricultural tasks • Data consistency and reliability • Scalability	• Crop Monitoring • Soil Monitoring • Environmental monitoring
4	(Chen et al. 2023)	China			• Sensors	• Cost effective • Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Data privacy and security • Scalability • Technical Expertise required for setup and maintenance	• Environmental monitoring • Soil Monitoring
5	(Damia Mohamad Razam & Sara Rais 2023)	Malaysia	• Mixed		• Sensors • Actuators • Connectivity protocols • User interfaces	• Automation of agricultural tasks • Real-time monitoring and data driven decision-making • Scalability challenges	• Soil Monitoring • Water Management
6	(Garg et al. 2023)	India	• Quantitative		• Sensors • Connectivity Protocols • Cloud computing • Data analytics and machine learning	• Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Data consistency and reliability • Scalability challenges	• Plant disease detection • Soil Monitoring • Crop Monitoring

7	(Haji Daud, Patchmuthu & Wan 2022)	Brunei	Mixed		• Sensors • Connectivity Protocols • Actuators	• Automation of agricultural tasks • Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Data consistency and reliability • Powering the IoT system • Scalability • Data security and privacy • Coverage and connectivity	• Water Management
8	(Hasan et al. 2024)	Bangladesh	• Quantitative		• Sensors • Actuators • Connectivity protocols • Cloud computing • Data analytics and machine learning • User interfaces	• Increased Agricultural Productivity and efficiency • Automation of agricultural tasks • Data consistency and reliability • Technical Expertise required for setup and maintenance • Coverage and connectivity	• Soil Monitoring • Water Management • Nutrient monitoring
9	(Ikidid et al. 2021)	Morocco	• Quantitative		• Sensors • Actuators • Connectivity protocols • Data analytics and machine learning • User interfaces	• Real-time monitoring and data driven decision-making • Automation of agricultural tasks • Data consistency and reliability • Data security and privacy • Coverage and connectivity	• Soil Monitoring • Environmental monitoring
10	(Islam et al. 2021)	Australia	• Quantitative		• Sensors • Actuators • Connectivity protocols • Data analytics and machine learning • UAV	• Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Coverage and connectivity • Data privacy and security	• Crop Monitoring • Environmental monitoring • Pest Detections
11	(Jain, Bhati, Katre & Meshram 2021)	India	• Quantitative		• Sensors • Connectivity protocols • Cloud computing	• Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Scalability challenges • High investment • Technical Expertise required for setup and maintenance	• Environmental monitoring
12	(Jaiswal & Rawat 2021)	India			• Sensors • Actuators • Connectivity protocols • Cloud computing • Data analytics and machine learning • User interfaces	• Real-time monitoring and data driven decision-making immediate feedback • Increased Agricultural Productivity and efficiency • High investment • Coverage and connectivity • Data security and privacy • Scalability challenges • Technical Expertise required for setup and maintenance	• Crop Monitoring • Nutrient monitoring • Water management • Pest Detections • Plant Disease Detections
13	(Jayanthi et al. 2024)	India	• Quantitative		• Sensors • Actuators • Data analytics and machine Learning • User interfaces	• Automation of agricultural tasks • Real-time monitoring and data driven decision-making • Precision in Disease and Pest Detection • High investment • Data privacy and security • Technical Expertise required for setup and maintenance • Coverage and connectivity	• Crop Monitoring • Soil Monitoring • Environmental monitoring
14	(Kanaga Priya et al. 2023)	India	• Mixed		• Sensors • Actuators • Connectivity protocols • Cloud computing • Data analytics and machine learning • User interfaces	• Automation of agricultural tasks • Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Data consistency and reliability • Coverage and connectivity	• Soil Monitoring • Environmental monitoring • Water Management
15	(Kaur, Yadav & Gill 2023)	India	• Qualitative		• Sensors • Cloud computing • Data analytics and machine learning	• Cost effective • Increased Agricultural Productivity and efficiency • Data privacy and security • Technical Expertise required for setup and maintenance • Small and fragmented landholdings	• Soil Monitoring • Environmental monitoring
16	(Kumar K, Palani, Sundravadivelu, Senthilvel & Thirupurasundari 2023)	India	• Quantitative		• Sensors • Actuators • Data analytics and machine learning • Cloud computing • User interfaces	• Automation of agricultural tasks • Real-time monitoring and data driven decision-making • Data consistency and reliability • Technical Expertise required for setup and maintenance • High investment	• Environmental monitoring
17	(Kumaran et al. 2023)	India			• Sensors • Connectivity protocols • Data analytics and machine learning • User interfaces	• Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Precision in Disease and Pest Detection • Scalability challenges • High investment • Data privacy and security • Technical Expertise required for setup and maintenance	• Crop Monitoring
18	(Li, Hou, et al. 2023)	Turkey			• Sensors • Actuators • Connectivity Protocols • Cloud Computing • Edge Computing • Data Analytics and Machine Learning	• Increased Agricultural Productivity and efficiency • Real-time monitoring and data driven decision-making • High investment • Data consistency and reliability • Coverage and connectivity • Technical Expertise required for setup and maintenance	• Pest Detections • Plant Disease Detections • Soil Monitoring • Fruit Detections
19	(Myvizhi Selvi, Brindha, Ravichandran, Karthikeyan & Ramesh Chandar 2024)	India			• Sensors • Connectivity Protocols • Cloud computing • User Interfaces	• Real-time monitoring and data driven decision-making • Improved crop selection • Increased Agricultural Productivity and efficiency • Scalability challenges • Data privacy and security	• Environmental monitoring • Soil Monitoring

20	(Ojha, Misra & Raghuwanshi 2021)	India			• Sensors • Connectivity protocols • Cloud computing • Edge computing • Data analytics and machine learning • User interfaces	• Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Data privacy and security • Scalability challenges • High investment	• Water management • Soil Monitoring • Crop Monitoring • Environmental monitoring
21	(Pathiraja, Wijesinghe & Kumara 2024)	Sri Lanka	• Qualitative		• Sensors • Connectivity protocols • Cloud computing • User interfaces	• Portability • Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Data consistency and reliability • Scalability challenges	• Soil Monitoring
22	(Patil et al. 2023)	China	• Qualitative		• Sensors • Actuators	• Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Automation of agricultural tasks • High investment • Technical Expertise required for setup and maintenance	• Water management
23	(Petrellis 2021)	Greece	• Quantitative		• Sensors • Actuators • Data analytics and machine learning	• Simplicity and Extensibility • Real-time monitoring and data driven decision-making • Automation of agricultural tasks • Limited Scope of Evaluation • Image quality • High investment • Technical Expertise required for setup and maintenance	• Plant disease detection
24	(Priadharshini, Kavipriya, Kumar, Hariram & Kiruthika 2024)	India			• Sensors • Actuators • Connectivity protocols • User interfaces	• Cost effective • Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Scalability challenges • Technical Expertise required for setup and maintenance	• Water Management
25	(Rajasekaran et al. 2024)	India	• Quantitative		• Sensors • Connectivity protocols • Cloud computing • Data analytics and machine learning • User interfaces	• Real-time monitoring and data driven decision-making • Improved crop selection • Scalability challenges • High investment • Data privacy and security • Technical Expertise required for setup and maintenance	• Soil Monitoring • Nutrient monitoring
26	(Raman, Parvathy, Sapra, Sonule & Murugan 2023)	India	• Quantitative		• Sensors • Actuators • Connectivity protocols • Cloud computing • Edge computing • Data analytics and machine learning • User interfaces	• Automation of agricultural tasks • Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Technical Expertise required for setup and maintenance • High investment • Data consistency and reliability	• Environmental monitoring • Crop Monitoring
27	(Ransinghe et al. 2023)	Sri Lanka			• Sensors • Connectivity protocols • Cloud computing • Data analytics and machine learning • User interfaces	• Increased Agricultural Productivity and efficiency • Real-time monitoring and data driven decision-making • Data consistency and reliability	• Soil Monitoring • Environmental monitoring

28	(Santhosh Krishna et al. 2024)	India	• Quantitative		• Sensors • Connectivity protocols • Cloud computing • Data analytics and machine learning • User interfaces	• Real-time monitoring and data driven decision-making • Automation of agricultural tasks • High investment • Data privacy and security • Technical Expertise required for setup and maintenance • Coverage and connectivity	• Soil Monitoring • Water Management
29	(Sarathkumar et al. 2024)	India			• Sensors • Actuators • Connectivity protocols • Cloud computing • User interfaces	• Automation of agricultural tasks • Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Data consistency and reliability • Coverage and connectivity • Technical Expertise required for setup and maintenance • Scalability challenges	• Soil Monitoring • Environmental monitoring • Nutrient monitoring
30	(Shireshi & Raman 2024)	India	• Quantitative		• Sensors • Connectivity protocols • Cloud computing • Edge Computing • Data analytics and machine learning • User interfaces	• Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Automation of agricultural tasks • Data consistency and reliability • High investment • Technical Expertise required for setup and maintenance	• Soil Monitoring • Environmental monitoring
31	(Sun, Abdulghani, Imran & Abbasi 2020)	Thailand	• Quantitative		• Sensors • Cloud Computing • Connectivity Protocols • Data Analytics and Machine Learning	• Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Data consistency and reliability • Lack of pH Level Monitoring • No automation	• Soil Monitoring • Nutrient monitoring
32	(Thangammal, Poorna Saai & Murugesh 2024)	Brunei			• Sensors • Actuators • Connectivity protocols • Cloud computing • Data analytics and machine Learning • User interfaces	• Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Scalability challenges • Lack of plant disease detection	• Soil Monitoring • Environmental monitoring
33	(Venkatesh, Aadhira & Kathiravan 2024)	India	• Mixed		• Sensors • Actuators • Connectivity protocols • Edge computing • Data analytics and machine learning • User interfaces	• Automation of agricultural tasks • Real-time monitoring and data driven decision-making • Precision in Disease and Pest Detection • High investment • Data privacy and security • Scalability challenges	• Soil Monitoring • Crop Monitoring
34	(Vijh, Arpita, Bora, Gupta & Kumar 2024)	India			• Sensors • Actuators • Connectivity protocols • Cloud computing • User interfaces	• Real-time monitoring and data driven decision-making • Increased Agricultural Productivity and efficiency • Data consistency and reliability • Technical Expertise required for setup and maintenance • Scalability challenges	• Soil Monitoring • Environmental monitoring

3. Results

3.1 Number of Publications by Year

The number of agricultural publications focused on IoT has kept increasing over the past few years. There are more and more publications on IoT in agriculture which means more people and organizations are exploring its uses. 16 publications were recorded for year 2024 which underlines the current surge in research about this subject. Thanks to the progress of sensors, analytics solutions and connectivity systems, there have been better agricultural IoT applications developed and put into operation. A higher level of awareness among researchers and businesses in agriculture and their adoption of IoT has caused a rise in research papers on IoT. An increasing number of published works in agricultural technology research may result from the government's efforts and funding (Li et al. 2023).

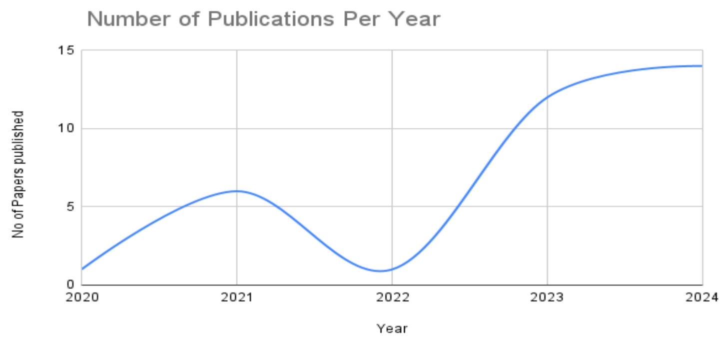

Figure 2. Analysis of publications by year of publication

3.2 Publications Per Continent

The Asian continent produced highest number of research studies totaling thirty in number. The majority of studies originate from India where twenty studies were conducted. The research encompasses Asian countries through China (2 studies), Bangladesh (1 paper) and Malaysia (1 paper) as well as Sri Lanka (2 studies) and Brunei (2 studies) and Thailand (1 paper). Research originating from Oceania consists of one paper and single institutions from Greece form the sole European representation in terms of contributions. The African continent has only one participating country in this research which is Morocco through a single paper. No research studies are found in North or South America within the analyzed dataset. The excessive number of research papers coming from Asian countries especially India suggests that this area has established itself as a major research hub focused on IoT for agricultural applications. The large number of rural residents in India who make up 57% of the population explains the low GDP percentage since agriculture remains the country's biggest industry (Sarathkumar et al. 2024).

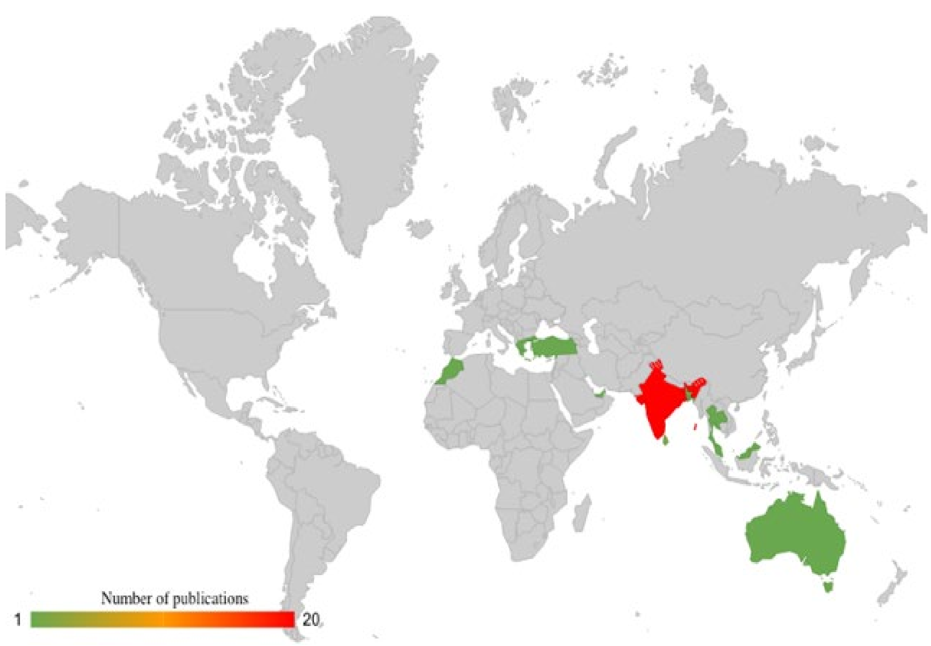

Figure 3. Graphical Presentation of Publications Per Continent.

3.3 Method trend Analysis

Out of 34 studies, there were n = 24 quantitative studies, n = 6 studies used mixed methods and n = 4 were qualitative studies. Most of the research is quantitative due to shared key features in IoT farming and quantitative study design. Most data gathered by IoT systems comes from devices, mainly sensors and actuators, that are linked together (Hasan et al. 2024).

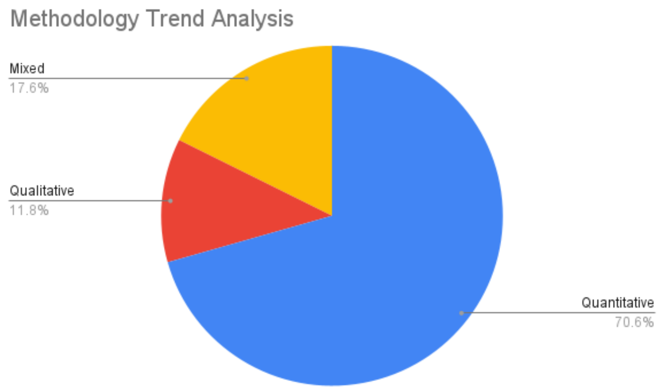

Figure 4. Graphical Presentation of Research methods.

The availability of large amounts of data supports using statistical methods and analysis for conducting quantitative investigation. Quantitative research is seen as most common, but qualitative and blended methods play a significant role as well. Whereas quantitative methods cannot provide in-depth details, these kinds of studies offer findings on how people see IoT in farming, along with the obstacles and consequences related to both society and the economy.

3.4 Frameworks

All 34 studies in the table do not mention or utilize any specific framework in their research methodologies.

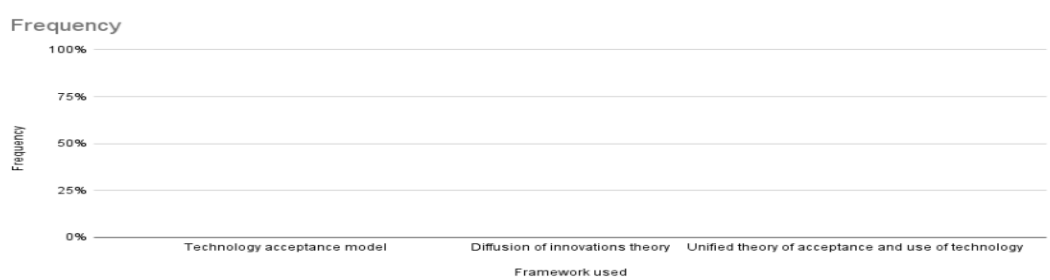

Figure 5. Graphical Presentation of Framework distribution

3.5 Utilization of IoT Technologies

Various studies look into the factors behind the integration of IoT in agriculture. Adoption of IoT in agriculture is influenced by different factors which can be divided into two distinct types: drivers and barriers. According to 25 out of the 34 analyzed research studies, improving the efficiency of farming is the main reason for using IoT technology. Monitoring activity and making decisions from data are considered the second most important factor, since they were mentioned in 31 out of 34 papers. Although “disease” and “pest” are only mentioned in three of the studies, correctly detecting these has become a major area of research. Cost savings were the primary reason why 3 out of 34 research studies concluded that implementing IoT in agriculture was beneficial. Information gathered by IoT can help choose better crops, as only a handful of the studied papers shared this benefit. Both data consistency and reliability are found to be key because they were mentioned by researchers in 16 of the studies.

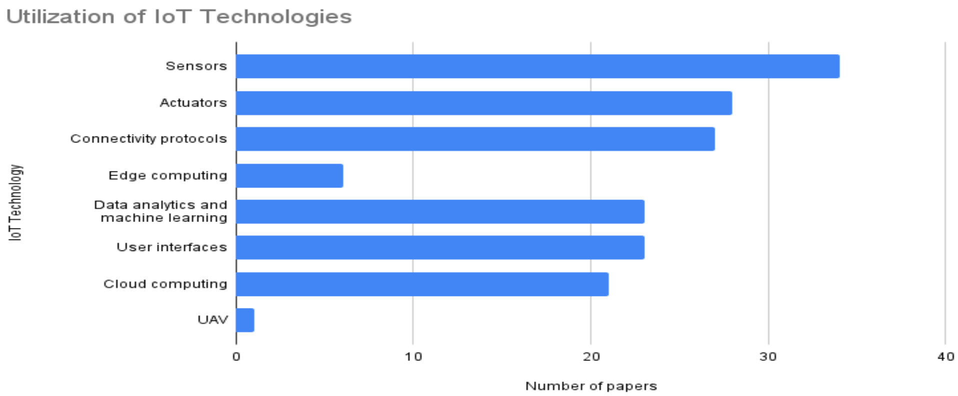

Figure 6. IoT technologies used

Of all technologies reviewed in the 34 studies, IoT sensors were found to be the most common. Sensors are valuable in agricultural IoT mainly because of what they can capture and send to machines. Based on the studies, actuators are used in many automated systems that respond to sensor data, as they appear in 28 out of 34 articles. It is also revealed that 27 of the 34 studies discuss how connectivity protocols are used. Data communication protocols introduced by Chavakula et al. (2024); Haji Daud et al. (2022) allow for connecting sensors, actuators, devices and central hubs reliably. Researchers using data analytics and machine learning (23) understand how crucial it is to find useful insights from the accumulated data (Oyinlola et al. 2020). A number of studies indicate that cloud computing is now the commonly used approach for managing data storage and processing in agriculture IoT systems. Twenty-three of the available 34 agricultural IoT applications use interfaces for farmers to connect with the systems and see information on outputs. Simple mobile applications and advanced dashboard software are both kinds of interfaces found in agricultural IoT. The examined studies suggest that edge computing and UAVs are key areas, but they only appeared in six out of the total 34 and one out of the total 34, respectively.

3.6 Key benefits and challenges analysis

Table 3. Drivers and barriers

Factor Category	Specific Factor	Number of studies
Drivers	Increased Agricultural Productivity and Efficiency	25
	Real-time monitoring and data-driven decision-making	31
	Automation of agricultural tasks	16
	Precision in Disease and Pest Detection	3
	Cost-Effectiveness	3
	Improved Crop Selection	2
	Data Consistency and Reliability	16
Barriers	High Investment	16
	Technical Expertise Required for Setup and Maintenance	20
	Scalability Challenges	14
	Data Privacy and Security	10
	Coverage and Connectivity	11

Using IoT in agriculture is becoming more popular, despite still facing challenges. Out of thirty-four research papers, the relatively high cost has been identified as a major obstacle in sixteen studies. The initial costs associated with IoT make it difficult for these small farms, as they have limited capital. Setup and maintenance often require strong technical skills and this barrier appears in 20 of the reviewed studies. Many regions that do not have enough qualified people to work on IoT systems may not use them as widely (Khan et al, 2023). In 14 out of 34 cases, the reports mention that increasing the size of agricultural operations with IoT is difficult. It is very challenging to link different parts of a large country smoothly using technology. Protecting the privacy and safety of information in IoT systems has been highlighted by ten of the thirty-four studies reviewed. Kumar et al. (2024) discovered that, since IoT devices collect much sensitive data in agriculture, both privacy and security of that data have to be secured. Thirteen out of 34 studies indicate that not having access to the internet in rural areas is a particular problem. According to the study (Narwane et al, 2022), IoT systems used in farming become unsuccessful when the internet is not dependable.

3.7 Application area

About 24 out of 34 studies examined the use of IoT for soil monitoring. Garg et al (2023) indicate that real-time data is essential for irrigation systems, nutrient care and soil evaluations on farms. Studies reporting on the effects of environmental factors on farming publish their results in 19 papers regarding the role of IoT monitoring techniques. Given the shortage of water in some areas used for farming, attention needs to be paid and 10 out of 34 studies point out how IoT can improve how water is used.

Table 4. IoT application area

Application Area	Number of studies
Soil Monitoring	24
Environmental monitoring	19
Water management	10
Crop monitoring	9
Nutrient monitoring	6
Plant disease detection	4
Pest Detection	3

Nine of the total 34 studies report that monitoring crops is a main use case for IoT. It has been found from research that IoT is used in observing crop health as well as the development and output of crops and in addition, IoT is being used to track and manage the nutrients in soil by six out of 34 studies. They regularly report on the NPK levels in the soil to help identify any nutritional shortcomings. Pests and diseases that reduce the crop yield have motivated 3 out of 34 studies to recommend using IoT for early identification. Automated identification in this system is made possible when IoT and image processing are combined with machine learning techniques.

4. Discussion

This section presents an in-depth analysis of the research findings and highlights areas where further investigation is needed for future studies.

4.1 IoT Technologies and Their Applications in Agriculture

The review presented the main IoT technologies used in smart agriculture. Studies by Ahmareen et al. (2024) and Kumar et al. (2024) found that sensors are common in the IoT because they support collecting data and analyzing the wellbeing of plants and crops in the field in real time. The primary data used in agricultural IoT comes from the sensors. Research reveals that sensors support the main idea by demonstrating that sustainable farming, improved productivity and flourishing operations are achievable (Chavakula et al. 2024; Rehman et al. 2022). When real-time data arrives from sensors, it starts irrigation to improve resource management and decision-making (Mehmood et al. 2022). According to Venkatesh et al. (2024) and Haji Daud et al. (2022), highlight that actuators are key elements in automating responses to sensor data. Thanks to these devices, commands from electrical sensors are turned into movements that let managers perform tasks immediately in their smart greenhouses. For developing efficient automated systems, especially in precision farming, combining sensors with actuators is necessary, since it supports quick monitoring and better control of resources which helps to improve crop yield (Ransinghe et al. 2023).

27 out of the 34 studies point out that by using these connectivity protocols, devices can communicate with and manage other devices in real time. According to Kumar et al. (2024), scientific research emphasizes that connectivity protocols help secure the stability of IoT data. As rural places have limited connectivity, it causes challenges in running IoT systems (Narwane et al 2022). In 23 out of 34 cases, research teams and farmers use analytical and machine learning algorithms to make important decisions in crop management. They supported this conclusion as well, explaining that data analytics highlights trends that make it easier to use resources wisely for better farm results. Research indicates that with machine learning, IoT technology improves health predictions for crops, yields and pest identification (Shetty & Smitha 2021). Though edge computing is not popular yet, it is gaining importance for some agriculture uses. According to Li et al. (2023), edge computing helps process data live at the farmsite. Edge computing is able to ensure

quick control over equipment and rapid data processing which is important for environmentally friendly farming nowadays.The majority of experts found that user interfaces are vital for sharing information between IoT systems and farmers. Hasan et al. (2024) insisted that it is crucial to design UIs adaptable to the needs of farmers and enabling them to perform their work even where there is no internet connection. Studies show that if the design is excellent, farmers can review their field data and control their IoT devices in real-time (Myvizhi Selvi et al. 2024).

Each of the 21 studies proves that cloud computing is the primary way data is stored and processed in agricultural IoT systems. The authors found that cloud computing is worthwhile for farmers since it makes their information available over the internet at any location. The literature summarized in Venkatesh et al.'s study states that cloud platforms used to keep agricultural information may be exposed to cyberattacks. One reference is made to Unmanned Aerial Vehicles (UAVs) in the study and these aircraft could greatly support agriculture by helping with observing crops and applying spray solutions where needed. Islam et al. (2021) found that UAVs are beneficial because they can transform aerial imaging by showing the condition and nutrients of different plants. The reviewed literature points out that there is not much discussion about UAVs and their integration with IoT. Also, further research is required to reveal what contribution these vehicles can make to farming.

4.2 Frameworks Used to Explain the Adoption of IoT in Agriculture

The research from these studies is in line with the core ideas found in models such as TAM, UTAUT and Diffusion of Innovations Theory. The basic principles of TAM for farmers are related to usefulness and simplicity since they employ IoT technology to enhance their work, achieve more efficiency and track situations in real time (Davis 1989). Because of its relatively high cost and the expertise needed, using IoT is not as simple as it seems (Shireshi and Raman 2024). UTAUT's predictions were right and the study also looked at performance expectancy, in addition to effort expectancy, social influence and facilitating conditions. The main part in gaining farmer confidence in IoT systems is their data being both reliable and consistent, according to (Ransinghe et al. 2023). Dealing with connectivity issues during the implementation of IoT shows the importance of set-up. Because of ongoing IoT research and development in Asian regions, various social influences occur, as shared trends and groups help new usage.

The adoption of IoT in agriculture receives additional understanding through the framework of Diffusion of Innovations Theory. Research activity and practical applications indicate IoT in agriculture progresses from early adoption toward early majority status. The diffusion of IoT technology needs to overcome barriers of cost and technical expertise and connectivity in order to reach the late majority and laggard categories (Miller 2023).

4.3 Applications of IoT in Agriculture

The review demonstrates how IoT applications benefit agriculture through their deployment for soil inspection as well as environmental surveillance, water management, crop observation and pest detection systems. Twenty four of thirty four studies demonstrate the significance of real-time soil data for optimizing irrigation schedules, fertilizer applications and crop selection. The analysis by Myvizhi Selvi et al. (2024) shows how IoT helps farmers make adjustments to their procedures through environmental factor monitoring which matches the findings of this study. According to Priadharshini et al. (2024) smart irrigation systems use IoT technology to save water resources while delivering the best possible crop conditions. Santhosh Krishna et al. (2024) showed how IoT crop monitoring technologies help farmers track crop health status and yield production while the authors agree with this approach.

4.4 Proposed conceptual framework

This framework describes the key reasons for using IoT in agriculture, its possible benefits, what challenges are involved and where this technology is being put to use. Fixing the difficulties and motivating new ideas will help everyone using IoT in agriculture do well.

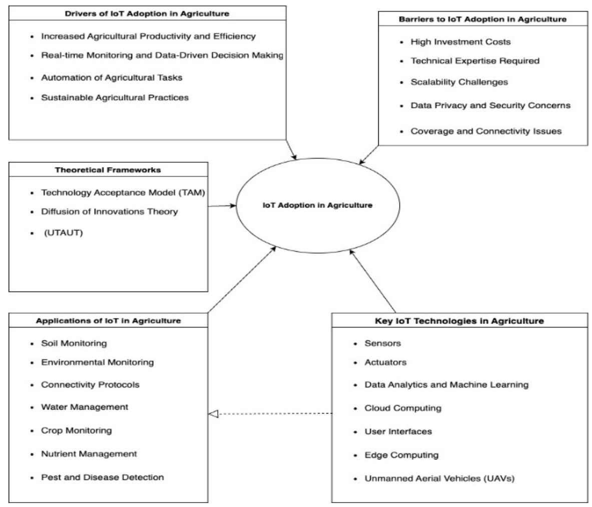

Figure 7. Conceptual Framework: An inclusive approach to the adoption of IoT in agriculture

It provides an overview of IoT in agriculture, describing the advantages, downsides and challenges in its usage. Allowing stakeholders to maximise the advantages and limit the downsides of IoT adoption.

5. Conclusion

The study investigated how IoT is improving precision farming, detailing its major drivers, problems and uses. According to the PRISMA guidelines, 34 peer-reviewed papers (2020–2022) were included in our review to investigate the use of IoT in agriculture. It was found that the usage of sensors, actuators and data analytics with IoT technologies increases productivity, efficiency and helps maintain sustainability. High price tags, tough technical rules and poor internet connections are obstacles to greater use of IoT. Using soil monitoring, water management and crop monitoring with IoT can enhance the effective use of resources and decision-making.

The findings highlight that IoT needs to be affordable and user-friendly, as well as have helpful policies, to help it become more popular in regions with scarce resources. Reviews are mostly recent and focus heavily on research done in Asia. In the future, scientists should examine a wider range of regions, new technologies (such as edge computing and UAVs) and the economic and social impacts, mainly for smallholder farmers. Addressing these issues with IoT can result in an agriculture sector that is more efficient, greener and stands up to challenges.

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