



ADVANCED INTERNATIONAL JOURNAL  
OF BUSINESS, ENTREPRENEURSHIP  
AND SMES  
(AIJBES)

[www.gaexcellence.com/aijbess](http://www.gaexcellence.com/aijbess)



## DIGITALIZATION AND INNOVATION IN AGRICULTURAL PRODUCTIVITY: A NARRATIVE REVIEW OF TRANSFORMATIVE TECHNOLOGIES AND FUTURE DIRECTIONS

Ahmad Zulhafizi Shahril Annuar<sup>1\*</sup>, Noor Zahirah Mohd Sidek<sup>2</sup>

<sup>1</sup> Faculty of Business Management, UiTM Kedah, Malaysia.

 [2023247026@student.uitm.edu.my](mailto:2023247026@student.uitm.edu.my)

 <https://orcid.org/0009-0004-8905-4888>

 [nzahirah@uitm.edu.my](mailto:nzahirah@uitm.edu.my)

 <https://orcid.org/0000-0001-5645-5790>

\*Corresponding Author

### Article Info:

#### Article history:

Received date: 30.07.2026

Revised date: 24.08.2026

Accepted date: 27.09.2026

Published date: 30.09.2026

#### To cite this document:

Annuar, A. Z. S., & Sidek, N. Z. M. (2026). Digitalization And Innovation in Agricultural Productivity: A Narrative Review of Transformative Technologies and Future Directions. *Advanced International Journal of Business Entrepreneurship and SMEs*, 8 (29), 1955-1973.

### Abstract:

This review explores how various digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), digital twins, and blockchain, impact and improve agricultural productivity. It also identifies barriers to the wide-scale implementation of these technologies. Literature was identified by a structured search of the Scopus database, and included peer-reviewed articles, book chapters, and proceeding publications, from 2023 to 2026. The publications were assessed by the review authors for inclusion based on whether the digital technologies described in the publications were linked to improvements in productivity or effectiveness. A narrative synthesis was performed based on 31 publications in this search, and supplemented by foundational publications. The literature was divided into four main groups. These were the use of IoT and Cyber-Physical Systems in farming, artificial intelligence in farming, blockchain and other technologies in farming and the supply chain, and barriers to the acceptance and adoption of farming technologies. The review identifies how digital tools help improve total factor productivity and the efficient use of resources within farms. However, the benefits are skewed where larger farms enjoy most of the benefits, while smaller farms continue to have challenges in adoption of digital tools. This is mostly attributed to capital and infrastructure constraints. More attention has been given to adopt individual digital technologies, compared to creation of a conducive innovation ecosystem to improve agricultural productivity. The review provides a framework to integrate the four key enablers and provide advice to stakeholders on ways to improve agricultural digitization in a sustainable and equitable manner.

**DOI:** 10.35631/AJBES.829112 **Keyword:**Agricultural Innovation, Agricultural Productivity, Artificial  
Intelligence In Agriculture

© The authors (2026). This is an Open Access article distributed under the terms of the Creative Commons Attribution (CC BY NC) (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact [aijb@gaexcellence.com](mailto:aijb@gaexcellence.com).

## Introduction

The challenges posed by a growing world population and the limited state-of-the-art possibilities to deal with the ecological consequences of climate change put agriculture in a dilemma. There are many innovative agricultural concepts that integrate digital technologies, e.g. AI, the Internet of Things, digital twins, robotics, and blockchain. If agriculture transforms in this way, it could lead to a more efficient and sustainable use of agricultural land and improve the resilience of ecosystems (Abdurakhmonova & Orzikulov, 2025; Vărzaru, 2025; Zhang & Zhu, 2025). Improving the productivity and sustainable use of agricultural land has positive impacts on the productivity of the global food system (Dong & Xu, 2026; Priya et al., 2026). Digital innovations in agriculture focus on the farming process and thus improve the productivity of the agricultural land (Abdurakhmonova & Orzikulov, 2025; Vărzaru, 2025).

Innovations in agricultural technologies (ag tech) have exploded in recent years. Simultaneously, challenges including lack of adequate policy and operational frameworks have slowed the growth of the sector. Inadequate digital and telecommunications infrastructure combined with insufficient 5G coverage create challenges in rural areas and specifically impact smallholder farmers in the Global South. Digital divide affects access to and the adoption of agricultural technologies. The digitization of the agricultural sector is moving at a faster pace than the public institutions charged with governing it. Technology is improving the productivity of large-scale farms, increasing the efficiency with which farms use agricultural inputs. Small farms, however, are facing challenges that deepen social and economic inequalities in the agricultural sector. The International Center for Agricultural Research in the Dry Areas (ICARDA) has identified the disparity between technological potential and the social and institutional infrastructure to utilize the technology. While several agricultural technologies exist to improve the efficiency of the agricultural sector, including post-harvest technologies, there are challenges with their availability and proper integration in the agricultural extension and other allied services.

The study on agricultural digital transformation is still divided. First, integrating the literature on agricultural digital transformation across various fields is difficult. Engineering and computer science literature focus on the design of smart agricultural systems. They do not study social and behavioral aspects of farm adoption. Consequently, the literature lacks an understanding of how farmers engage and interact with the technology. Finally, many of these studies focus on crops and ignore more complex farming systems (Jiménez-López et al., 2025;

Singh & Veeramanickam, 2026). Second, agricultural digital transformation is happening at an uneven pace. Agricultural transformation occurring in higher-income and more commercialized agricultural systems is more documented compared to lower-income systems (Ahirwar et al., 2025; Singh & Shukla, 2026). There is also a lack of agreement on definitions for the various concepts and models in the literature on agricultural digital transformation. Finally, different organizational and business models for agricultural digital transformation have been developed. Consequently, farmers and policymakers have difficulty navigating the various models and determining the best options for scale (Dong & Xu, 2026; Akimbekova et al., 2025).

Because of the gaps in the existing literature, a narrative review is needed to integrate the most recent information and assess the potential of farming systems to accept and integrate various digital innovations. This review explores various digital innovations, and the socio-technical and institutional factors that determine their acceptance and integration. The review also addresses the following questions: What do that that recent evidence say about the productivity potential of the innovation groups? Who do that evidence and literature say capture the gains? What are the barriers for the gainers to reach small-scale and large-scale farmers? The review is organized into five chapters. The first chapter describes the methodology of the review and the guidelines that were used to limit the search. The second chapter describes the theory and gives definitions that were used in the review. The third chapter describes and interprets the body of literature on Digital Agriculture. The fourth chapter describes barriers to the adoption of innovative digital agricultural systems. The last chapter contains the authors' personal opinions and suggestions to support and encourage the adoption and use of digital agricultural systems.

## Review Approach

A structured approach was taken to locate and select studies in order to provide an adequate level of detail in this review while ensuring methodological transparency and accuracy (Green et al., 2006; Snyder, 2019). A core attribute of a systematic review is the pooling of research through a synthesis of their findings. A narrative review, however, may construct an argument based on a synthesis of theory to address research gaps and critique new innovative systems (Green et al., 2006; Snyder, 2019). This review is composed of two parts. The first part consists of the search and selection of studies and comprises a systematic review of the literature. The second part of the review incorporates and interprets the findings of the studies in an integrative and theory-based way. It is important to note that the findings in the review do not represent a synthesis of effect sizes. Rather, the findings of the review comprise studies integratively interrelated to form a core element of the review's argument.

As no protocol was registered and no formal quality assessment was performed, no meta-analysis was conducted, and the review is thus considered a non-systematic review. In the opinion of the author, this review is more correctly termed a "semi-systematic review." According to Snyder (2019), in a semi-systematic review, while the search strategy is not registered, it is adequately described, and findings are synthesized in an accessible manner, typically in a narrative fashion. The author relied on the Scopus database to locate the literature. Scopus is a multidisciplinary database that comprises peer reviewed literature across disciplines including agricultural sciences, engineering, and physical and social sciences. Other literature sources such as Web of Science, Google Scholar, and "grey literature" were not searched. Restrictions in literature searching are recognized as shortcomings.

Literature identification was conducted using a target publication timeframe spanning 2023 to 2026, capturing the most recent technological advancements, empirical evaluations, and socio-technical developments in digital agriculture. The search was executed across article titles, abstracts, and keywords using the following explicit Boolean search string:

("digitalization" OR "digital transformation" OR "digitization" OR "e-agriculture") AND ("innovation" OR "novelty" OR "advancement" OR "improvement") AND ("agriculture" OR "farming" OR "agricultural" OR "crop") AND ("productivity" OR "efficiency" OR "yield" OR "output")

The selection process combined several qualitative evaluations with a view to progressively eliminating irrelevant documents. The first search of the bibliographic database primarily included English language publications, i.e., peer reviewed journal articles, book chapters, and conference papers, and appeared in the indexed literature in the specified period. The second search included peer reviewed articles published in English, and other articles including chapters, proceeding papers, and editorials. It also included academic, practitioner and other works, and reports. The articles were required to include and integrate digital technologies and innovation (e.g. AI, IoT, digital twins, and sensors) that influence and enhance agricultural productivity and resource use. Other articles, including book chapters, proceedings and editorials, that focused on the integration of digital technologies in other areas and industries, and studies that do not include a research or practical framework, were excluded. Scopus searches generated [n] articles. After removal of duplicates, [n] articles were assessed for eligibility. The remaining articles (n = 31) comprise the 2023 to 2026 cited articles in the thematic review. Additional 14 articles, published prior to 2023, were cited in these 31 articles, and were identified through backward citation searching. These articles presented the foundational and conceptual background of digital and precision agriculture. A summary of the overall search strategy is presented in Table 1 below.

**Table 1: Summary of Search Strategy and Selection Parameters**

| Component          | Description                                                                                                                                                                                                                                                                    |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Primary Keywords   | "Digitalization", "Digital Transformation", "Agricultural Productivity", "Agricultural Innovation", "Precision Farming"                                                                                                                                                        |
| Secondary Keywords | "IoT in Agriculture", "Predictive Analytics", "Digital Twins", "Blockchain Traceability", "Digital Extension", "Smart Farming"                                                                                                                                                 |
| Search Strings     | ("digitalization" OR "digital transformation" OR "digitization" OR "e-agriculture") AND ("innovation" OR "novelty" OR "advancement" OR "improvement") AND ("agriculture" OR "farming" OR "agricultural" OR "crop") AND ("productivity" OR "efficiency" OR "yield" OR "output") |
| Publication Years  | 2023 – 2026                                                                                                                                                                                                                                                                    |
| Inclusion Criteria | Peer-reviewed journal articles, book chapters, and indexed conference proceedings.<br>Written in the English language.<br>Published between 2023 and 2026.<br>Explicit focus on digital technologies, ag-tech innovations, or digital transformation.                          |

|                           |                                                                                                                                                                                                                                                                                                      |
|---------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                           | Contextualized within crop/livestock production, total factor productivity, farm efficiency, or socio-technical adoption dynamics.                                                                                                                                                                   |
| <b>Exclusion Criteria</b> | Non-peer-reviewed opinion pieces, short editorials, and gray literature.<br>Studies focused strictly on non-agricultural industry sectors.<br>Articles lacking conceptual depth, empirical data, or clear methodological frameworks.<br>Duplicate or redundant publications across database exports. |
| <b>Studies Retained</b>   | 31 publications (2023 to 2026) from the Scopus search; 14 earlier foundational works added through backward citation for the conceptual background only                                                                                                                                              |

## Conceptual Background

### *Definitions*

Shared definitions of terms are important for comparing and integrating research in different branches of knowledge. Thus, within agricultural and computer sciences, digitization signifies the conversion of agricultural variables, including soil and air temperatures, soil and air moisture, crop and weed canopy, and others, from analog to digital form (Ahirwar et al., 2025; Postolache et al., 2025). From a sociotechnical perspective and building on the definition of digitization, digitalization is the integration of information and communication technologies, and various devices and equipment within the organizational structure and processes of the agri-food chain (Abdurakhmonova & Orzikulov, 2025; Hajiyeva, 2025). Still within the scope of various perspectives, the comprehensive transformation of a country's agricultural sector as a result of the convergence of smart agricultural technologies is digital transformation (Akimbekova et al., 2025; Dong & Xu, 2026). These smart agricultural technologies provide the means for the site-specific management of agricultural fields and are building blocks of the more recent advances in digitalization in agriculture. (Adrian et al., 2004; Venable, 2008; Zhang et al., 2002).

At the same time, setting limits for the concepts of innovation and productivity in agricultural systems is essential for analyzing results and achievements. Innovation in agriculture refers to the using of new or improved agricultural technologies, systems and strategies in the farming business (Priya et al., 2026; Singh and Shukla, 2026). Innovation is sometimes viewed as the use of new farm equipment and machines. Recently, scholars viewed agricultural innovation as the use of a combination of different farm equipment, technologies and strategies in an integrated approach (Priya et al., 2026). Increasing agricultural productivity and ensuring that existing agricultural land and other agricultural resources are fully utilized can be achieved through the use of various techniques and approaches including the integration of different farm machines, equipment and agricultural technologies (Abdurakhmonova and Orzikulov, 2025; Zhang and Zhu, 2025). Use of farm equipment and machines equipped with digital technology can play a key role in improving the productivity of agricultural land and other agricultural resources (Babbar et al., 2025; Vărzaru, 2025).

## ***Key Theories and Framework***

### ***Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT)***

TAM and UTAUT models focus on individual acceptance of and use of technology. These models provide the most comprehensive approaches for analyzing farm-level technology acceptance and use behavior (Davis, 1989; Venkatesh et al., 2003). TAM concentrates on individual's acceptance of and use of technology in the form of software or other information systems. In this regard, TAM suggests that individuals' acceptance and use of a given technology is influenced by two constructs, namely Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) (Davis, 1989). UTAUT extends the theory and includes social influence, performance expectancy, and effort expectancy, and also considers other contextual conditions or influences, as part of the construct of use behavior (Venkatesh et al., 2003). In the case of smallholder farmers, farm managers, and other agriculture extension agents, the absence of necessary ICT infrastructure to support modern ICT systems negatively impacts the perceived ease of use of such systems (Sankati et al., 2025; Singh et al., 2025).

### ***Diffusion of Innovations Theory (DOI)***

Rogers' (2003) Diffusion of Innovations (DOI) theory allows for an analysis of the trends and factors influencing the spread of agricultural innovations. As defined by DOI, innovators and early adopters tend to be more "forward looking" and less constrained by the social and structural norms of their environment. The rate at which an innovation is accepted is also dependent on the relative advantage, compatibility, complexity, trialability, and observability of the innovation. In agricultural innovations, the relative advantage of an innovation can be enhanced by incorporating the principles of comparative advantage. The challenge of an innovation being complex can be reduced by promoting the complementarity of the innovation. Given the right environment and adequate support, various agricultural innovations can be developed and adopted (World Bank, 2012).

### ***Socio-Technical Systems (STS) and Agricultural Innovation Systems (AIS)***

Digital and other innovations are best integrated within agrarian systems by using a combination of the Socio-Technical Systems (STS) approach and the Agricultural Innovation Systems (AIS) framework (World Bank, 2012). The STS approach is focused at the meso-level of the agricultural sector and emphasizes the integration of suitable technology within the governance framework (Geels, 2004). Similar to STS, the AIS approach is also meso-level focused, but emphasizes governance, public-private partnerships and collaboration in integration of IT and communication (IC) innovations to agriculture (Priya et al, 2026).

Rural agriculture can be transformed using integrative, adaptive systems, but successful and sustainable transformation is dependent on the coordinated efforts of several public and private agencies (Hajiyeva, 2025; Dong and Xu, 2026).

## ***Thematic Review of Literature***

The aim of this narrative review is to analyze and interpret the various dimensions of agricultural digitalization. It repositions the focus away from an exhaustive study-by-study examination of primary literature to a thematic synthesis of the literature. Organizing the body

of knowledge on the subject into thematic fields helps reveal the pillars of the technology, the comparable studies, and the social and technological phenomena that cut across the food production system. In this review, the literature has been synthesized into four main thematic areas. The first area analyzes cyber-physical systems and the Internet of Things in precision farming. The second area analyzes artificial intelligence and various forms of predictive intelligence. The third area analyzes the use of blockchain technology to improve the transparency and traceability of food supply chains. The last area synthesizes the socio-technical aspects of the use of digital tools in agriculture. The first three thematic areas primarily emphasize the use of various digital tools and systems to enhance food production, while the last thematic area analyzes the socio-technical barriers that affect the widescale adoption of digital agricultural tools. The first three thematic areas will be referred to as the digital innovation ecosystem, while the last thematic area will be referred to as socio-technical digital adoption. The structural relationship between these themes is illustrated in Figure 1.

### ***Theme 1: Cyber-Physical Systems and IoT Infrastructure in Precision Farming***

There is a growing body of research focused on integrating the Internet of Things (IoT) and cyber-physical systems to develop next-generation farming technologies. The primary focus of this research is the development of cutting-edge technologies for sensing and analyzing soil and climate conditions, as well as plant health. Further, these technologies facilitate the automated and continuous monitoring of various parameters that help in timely and precision farming. The deployment of these cyber-physical systems and the Internet of Things changes the way a farm manager manages his or her agricultural land. Traditionally, farm managers would use his or her experience and best practices to manage the farm. Now, with these systems, managers are able to implement truly precise agriculture. It is important to note that, the combination of 5G and Edge computing, further facilitates real-time management and control of farming activities, and optimally utilizes farm resources. This has the potential to transform the Total Factor Productivity of a farm.

There is widespread consensus on the possibilities that agricultural Internet of Things (IoT) technologies provide. However, opinions and findings in scholarly and peer-reviewed literature vary on the extent to which a given system can be scaled; how well such systems can interact with one another; and whether the systems are financially viable. A considerable body of literature in the field of agricultural engineering focuses on large commercial farms and greenhouses (Babbar et al., 2025; Farzana Tasneem & Achar, 2024). Other literature focuses on smallholder farms and presents various socioeconomic challenges in integrating IoT technologies (Artykmyradov et al., 2025; Sankati et al., 2025). Various opinions exist regarding the focus of research and development (R&D) efforts. Some authors argue that the emphasis should be on the development of end-to-end, integrated platforms (Ahirwar et al., 2025), while others support the development of networks of low-cost, modular sensors (Jiménez-López et al., 2025). The authors of some recent studies argue that in addition to the capital costs, the operational costs of developing and using such systems remain high (Zhang & Zhu, 2025; Artykmyradov et al., 2025).

Studies on agricultural cyber-physical systems have focused on hardware installation and data collection. They have not considered the important aspects of long-term data management and retention. Hardware is expected to withstand various environmental conditions and remain functional for a long time. Sensor networks are expected to provide data over a long period. IoT systems in agriculture have been studied over a short period, and the focus has been on the

performance of the systems. No studies have examined the resilience of sensor networks and the ability of IoT systems to function over a long period (Babbar et al., 2025; Kamal & Saxena, 2026). Systems depend on hardware that is manufactured by different companies. Communication protocols enable integration of hardware systems. The main reason that hardware systems manufactured by different companies are integrated is because of the absence of protocols that integrate sensor networks. Farm level acceptance of IoT systems in agriculture is dependent on the existence of standardized communication and integration protocols. The purpose of this review has been to identify the barriers that impede productivity. Hardware systems are expected to function and remain stable for an extended period.

### ***Theme 2: AI, Predictive Analytics, and Digital Twin Technology***

Kamilaris et al. (2017) and Wolfert et al. (2017) place Artificial Intelligence (AI), Machine Learning (ML), and Digital Twins (DTs) within the cognitive layer of agricultural digital transformation. They illustrate how, through data science, various crops can be diagnosed for condition, potential yields can be estimated, and pest and disease conditions can be anticipated (Agrawal & Kumar, 2025; Bhanu et al., 2026; Ugwu et al., 2025). Digital Farming Twin Systems, like other DTs, create a virtual representation of a farming system. The representations can utilize various inputs to simulate the growth of crops and the health of livestock and can integrate various weather and environmental conditions to create virtual representations of farming systems (Postolache et al., 2025; Singh & Veeramanickam, 2026). Ultimately, crop and livestock farmers can utilize these representations and systems to maximize the potential of their crop and livestock yields (Kumar & Sharma, 2025; Vărzaru, 2025).

A review of recent works shows that there is not always consensus on the generalizability of algorithms, and the transparency of the models used to represent different agricultural systems. Some works have shown that models can be trained to accurately predict agronomic variables using benchmarked datasets. However, several authors have highlighted the fact that AI models that have been trained using large datasets often lack the generality to make accurate predictions in real-world agricultural scenarios. This is because agricultural systems are very complex and combinations of different factors (e.g. different soil conditions, climate, etc.) can influence plant growth. Some critics of the Digital Twin (DT) framework have argued that DTs can enable the optimization of integrated agriculture systems but have noted that the real-time representation of such systems would require a lot of data and computational power, as well as sophisticated models (Hossain & Ghosh, 2026; Singh & Shukla, 2026).

This domain shows a major discrepancy between creating algorithms and incorporating them in an operational Decision Support System (DSS) for farming. Most papers describe computer simulations (Bhanu et al., 2026; Ugwu et al., 2025). There is a lack of evidence on the influence of AI recommendations on farmers' behavior and changes in farmers' productivity. Additionally, several papers address the trust gap, which means farmers do not adopt suggestions provided by complex machine learning models because they do not provide an explanation for their recommendations (Kumar & Sharma, 2025; Vărzaru, 2025). Explaining the recommendations provided by a machine learning model is important for farmers to trust the recommendations. This review focuses on the lack of descriptions of practical cases (e.g. commercialization) and integration of AI-based systems for Agriculture 5.0, to create a framework to identify the barriers for the realization of the vision of Agriculture 5.0.

***Theme 3: Supply Chain Transparency, Traceability, and Blockchain***

Beyond the farm, blockchain provides a framework for post-harvest processes, transportation, and distribution. Decentralized record keeping using blockchain, combined with IoT, can create a verifiable, irreversible record of the status, location, and quality of agricultural produce from the field to the consumer (Bharat Babu et al., 2023; Sravani and Veeranjanyulu, 2025; Vignesh et al., 2025). This has the potential to transform food safety, quality, and supply chain management (Hiremath and Hiremath, 2024; Vignesh et al., 2025). Timely and efficient supply chain management leads to loss reduction. Cold chain management is one of the means to achieve this. Blockchain, combined with other technological advances, has the potential to transform food systems by improving food safety and reducing reliance on intermediaries (Akimbekova et al., 2025; Bharat Babu et al., 2023).

Literature on blockchain technology outlines salient concerns related to scale, energy use, and the fidelity of recorded data. Proponents of the technology view blockchain as a means to ensure end-to-end trust in supply chains. Meanwhile, economists and other officials focus on the “garbage-in, garbage-out” phenomenon, in which fraudulent or erroneous data, perhaps entered at the farm level, becomes permanently incorrect, but validated, in the blockchain. Other scholars note that blockchain adoption is economically viable for the inter- (or international) trade of high-value agricultural products, but not for staple foods.

Research on the use of blockchain in the agriculture value chain is still at the conceptual and preliminary stage. This makes little or no information on the effect of the use of blockchain on agriculture value chains, and associated costs and benefits. This is evidenced by the paucity of information on the barriers that constrain the adoption of blockchain technology. As shown in this review, achieving the Sustainable Development Goal 2 on ending hunger, is as important as improving the productivity of farmland. Therefore, as important as increasing farm production is developing post-harvest supply chain systems to ensure the farm produce is promptly distributed.

***Theme 4: Socio-Technical Adoption Dynamics, Digital Extensions, and Innovation Ecosystems***

Socio-technical factors largely determine the actual transformation of agricultural digital innovations at scale. Reviewed literature acknowledges that a progressive approach to digital transformation of agriculture should move beyond the traditional frame of technology diffusion to encompass integration of various public and private actors along the innovation value chain. These include service delivery systems, extension systems and farmers' organizations. Digital extension aids, including mobile-based services and applications, have the potential to facilitate the training and improvement of farmers' digital and ICT literacy. This can facilitate the rapid adoption of agricultural innovations. If adequately customized to various socio-cultural contexts, digital extension aids and related ICT infrastructures can improve the adaptive capacity of agriculture. This can increase farm productivity and contribute to poverty reduction (Zhang & Zhu, 2025; Dong & Xu, 2026).

A review of socio-technical studies has identified the main polarized opinions on the digital divide, equity in access to technology, and the effects of upper- versus lower-tier extension. Some researchers believe that, with the help of digital technologies, extension workers can provide smallholder farmers with access to more advanced agricultural advice (Sankati et al.,

2025; Sharma & Tyagi, 2023). Other researchers have analyzed cases where digital technologies have increased social and economic inequalities (Artykmyradov et al., 2025; Singh et al., 2025). Still, others have addressed the design of the digital infrastructure (centralized vs. decentralized) and the digital technologies employed in the agricultural sector (Dong & Xu, 2026; Priya et al., 2026). Some researchers support the use of AI to provide agricultural extension services (Sharma & Tyagi, 2023; Singh et al., 2025), while others believe that extension workers play a vital role in providing agricultural extension services through personal relations and social networks.

Reviewing socio-technical literature shows that long-term impacts of digital agriculture, especially changes in society and institutions, is an under researched area. Most studies concentrate on farmers' technology acceptance and include TAM or UTAUT in their work. Post-acceptance technology use, the reasons for giving up technology, and the ways users adapt the technology to suit their needs are some of the major gaps in research on farm level digital adoption (Artykmyradov et al., 2025; Sankati et al., 2025). Longitudinal evaluations of public policies to address digital divides and their adverse effect on the farm level technology innovation ecosystem are few and far between (Dong & Xu, 2026; Priya et al., 2026). This paper concentrates on institution building. Although farmer-centered and appropriate technologies can improve agriculture, political will and commitment to improve farm level productivity and rural transformation is as important.

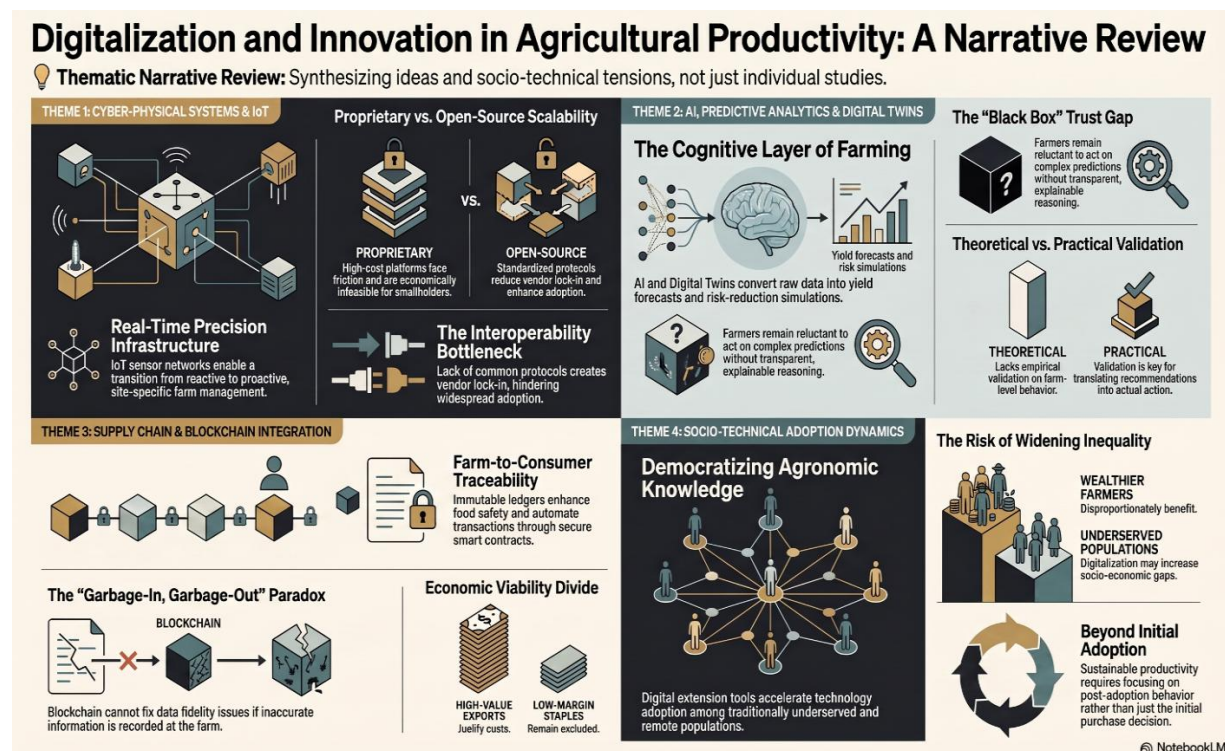


Figure 1: Thematic Review of Literature

## Critical Discussion

This section provides a critical analysis of literature on digital transformation and agricultural productivity. It moves away from singular, descriptive accounts of agricultural technologies.

The analysis covers four elements. Agreements element captures different views on the same idea or concept. Disagreements element covers diverse views that are contradictory. Gaps element captures missing links. Implications element captures insights literature offers for framing policies and improving extension services. The analysis identifies literature gaps and provides policy directions and actions for agricultural transformation.

### **Agreements in Literature**

A consensus exists that integration of digital technologies in agricultural systems improves TFP. (Abdurakhmonova & Orzikulov, 2025; Zhang & Zhu, 2025). Variable rate technology for agricultural inputs has been positively evaluated by scholars. Scholars attributed the positive impacts to the use of Internet of Things (IoT) in conjunction with remote sensing (Ahirwar et al., 2025; Babbar et al., 2025; Mrudula et al., 2026; Sarma et al., 2026). Integration of digital technologies in agricultural systems has been associated with positive changes in agricultural systems and in reducing environmental damages (Hossain & Ghosh, 2026; Singh & Shukla, 2026).

There is a general consensus that, in the absence of adequate institutions, the benefits of the Green Revolution will not be sustainably realized. The literature shows that the successful implementation of e-agriculture hinges on an innovation ecosystem that comprises public, private, and research components (Dong & Xu, 2026; Priya et al., 2026; Singh et al., 2025). Therefore, advances in technology, hardware and software, are not sufficient for transforming agriculture. Other factors, such as the availability of the skilled workforce and other human resources for the development of agricultural extension services, are equally important (Sankati et al., 2025; Sharma & Tyagi, 2023).

### **Disagreements**

Although the potential of smart farming is recognized at a broader level, numerous/diverse/varied views are present on the potential for equitable improvement and the limits of smart farming. The concept of the Internet of Things (IoT) and Artificial Intelligence (AI) is relatively new. Positive and overwhelming views are present in the literature on the potential of these technologies for improving the productivity and profitability of the farming sector (Babbar et al., 2025; Farzana Tasneem & Achar, 2024). However, some authors have rejected the notion that the Digital Divide will have a positive impact on the distribution of wealth and alleviate poverty (Sharma & Tyagi, 2023). Others maintain that the impact of the Digital Divide will be adversarial and exacerbate the existing conditions in agriculture (Artykmyradov et al., 2025; Zhang & Zhu, 2025).

There is also debate concerning data governance, system interoperability, and centralization. Suppliers of proprietary farming solutions, based on platform ecosystems, claim that their solutions enable better user experiences, and improve data protection and the accuracy of predictions (Agrawal & Kumar, 2025; Vărzaru, 2025). Other researchers and decreased access and control over data, and increased dependence on a single vendor in the supply chain (Ahirwar et al., 2025; Dong & Xu, 2026). There is also scientific uncertainty concerning the benefits of using blockchain technology to track agricultural commodities (Akimbekova et al., 2025; Hiremath & Hiremath, 2024).

There are considerable research gaps and limitations in the body of knowledge on the digitalization of agriculture. There is an imbalance in research design and methodology. The majority of studies are largely theory- and methodology- light, focusing on a single snapshot of time, and simulation-based computing (Bhanu et al., 2026; Ugwu et al., 2025). There are very few field studies focused on long-term research (Artykmyradov et al., 2025; Kamal & Saxena, 2026). Most behavioral adaptation and farm management models are equally light on theory and fail to capture the full range of human behavior, including the reasons for discontinuance of digital farming solutions (Sankati et al., 2025; Singh et al., 2025).

Publications tend to focus on higher-value cereals and horticulture chains in North America, Europe and East Asia. Other chains in Latin America and Sub-Saharan Africa, including subsistence agriculture and more complex agro-forestry systems and livestock production, are largely absent in the research (Dong & Xu, 2026; Postolache et al., 2025; Zhang & Zhu, 2025; Jiménez-López et al., 2025; Singh & Veeramanickam, 2026). Additionally, the research focuses on primary production. Therefore, it does not consider the lifecycles of the digital hardware and systems employed in smart agriculture. As such, the body of knowledge is substantively lacking with respect to the waste and toxic byproducts of digitization and computation in smart agriculture, as well as the net energy impacts of these systems (Ahirwar et al., 2025; Hossain & Ghosh, 2026).

## **Implications**

The insights reported herein have a range of research, policy, and extension service implications. Regarding research and extension activities, the continued presence of the digital divide means that efforts to integrate ICTs in agricultural development should progress from a predominantly supply-side to a demand-side focus. The challenge of the digital divide should be confronted through the integration of various digital technologies, including open source and/or programmable software and hardware. In addition, digital extension services should address local situation analyses to identify useful digital technologies for the situation. The integration of XAI, especially in the area of agriculture, should be based on a partnership of computer scientists and agricultural experts (Kumar & Sharma, 2025; Vărzaru, 2025).

On the policy and governance fronts, national and regional policies should define farmers' right to or ensure access to safe and secure agricultural data, promote competition, and safeguard farmers' interests (Dong & Xu, 2026; Hajiyeva, 2025). Public funding should be directed to create and expand digital and data infrastructure for agriculture, including broadband and other communication services in rural areas (Akimbekova et al., 2025; Priya et al., 2026). In all their future studies, researchers should take a holistic view of the socio-ecological and economic impacts of digitally based innovations. The goal should be to promote the integration of digital innovations in the agriculture sector for the achievement of the SDGs (Hossain & Ghosh, 2026; Singh & Shukla, 2026).

## ***Suggestions and Areas for Future Work***

Realizing the productivity potential of digital agriculture will rely on the integration of people, machines, and processes. To move beyond the pilot stage, it will be necessary to address institutional, economic and physical barriers. This research has synthesized and described the state of the art and identified gaps in this area. Consequently, the recommendations presented

in this report are strategic and focus on barriers and enabling conditions for each of the four thematic layers of the conceptual framework.

Achieving the productive potential of digital agriculture depends on sensing, computing and connectivity infrastructure, adequate data and the interoperability of hardware, as well as decision support systems. The effective use of these systems, however, depends on adoption by farmers, which is often complicated by institutional and infrastructural barriers. The recommendations in this review focus on technologies and make no consideration for the political economy of the context in which the technologies are implemented.

### ***Recommendations for Practice***

Improvements in digital agriculture practices have the potential to improve agricultural output around the world. To help achieve this goal, practitioners, such as farm managers and extension agents, should no longer focus on acquiring agricultural technologies on an individual basis. Instead, these practitioners should be encouraged to use integrated modular systems (IMSS) that are appropriate for the situation. Modular systems offer a greater potential for future growth and integration. Additionally, farm managers should look for more flexible, interoperable devices, and farm management systems (Ahirwar et al., 2025; Babbar et al., 2025).

There are a number of systems that use AI to help farmers make decision about farm management. However, farmers are often hesitant to fully rely on such systems because of a lack of trust. In order to build trust, systems should integrate explanations with AI recommendations. Additionally, farm management systems should be integrated with local farm practitioners' understanding of agriculture and IMSS (Kumar & Sharma, 2025; Vărzaru, 2025). Extension agents should also ensure that the farm management systems deployed help improve local farmers' digital skills and data literacy (Singh et al., 2025; Sankati et al., 2025).

### ***Recommendations for Policy or Organizational Use***

Public and private organizations involved in agricultural development should use governance mechanisms to foster inclusive digital transformation. For rural areas, the government should increase its infrastructure investments to provide high-speed and high-quality Internet, such as a rural 5G network, to promote digital equality for farmers. The government should also implement a regulatory framework to address the farm data and algorithmic issues. Such regulation should foster farm data protection and promote digital equality for farmers. To facilitate farmer-to-farmgate digital connections and empower farmers, donor agencies and funding organizations should encourage and support the establishment of open-access agriculture innovation ecosystems (Akimbekova et al., 2025).

### ***Future Research***

Resolving critical gaps and blind spots in the literature will be the focus of future research. Some of these gaps include: The influence of climate change on the lifecycle of IoT and Cyber-Physical Systems and Digital Farming. Are there disadoptions? What are the ReOS and ROIs of these systems? (Artykmyradov et al., 2025; Kamal & Saxena, 2026) Next, the focus should be on digital agriculture in developing countries, especially agroforestry and small livestock farming systems. (Jiménez-López et al., 2025; Sankati et al., 2025; Singh & Veeramanickam,

2026). Finally, research should address the socio-ecological limits and impacts of digital agriculture, including the environmental costs of digital farming, e-waste, and the energy footprint of AI. (Ahirwar et al., 2025; Hossain & Ghosh, 2026).

## **Conclusion and Limitations**

This final section draws the review together and sets out its limitations.

### ***Conclusion***

This narrative synthesis summarizes the various articles that discuss digitization of agriculture. It demonstrates integration of cyber physical systems, Artificial Intelligence, post-harvest blockchain, and innovation ecosystems, and its impact on the agricultural productivity (Abdurakhmonova & Orzikulov, 2025; Dong & Xu, 2026; Singh & Shukla, 2026). The articles in this synthesis have been categorized into four sections based on the themes, and have gone beyond, describe the technologies and bring out the key challenges and drivers of Agriculture 5.0. The articles have discussed the use of advanced technologies and innovations for agriculture to improve and optimize the agricultural input and output management. The use of advanced technologies has improved transparency and visibility in the agriculture supply chain.

However, the impact of the innovations has been limited due to several social and technological factors (Sankati et al., 2025; Singh et al., 2025). Most of the improvements and gains have been recorded for large scale agricultural producers. For small scale agricultural producers, the impact has been very limited. Policies to benefit small scale agricultural producers have not focused on improving the needed extenders, data standards, and governance to strengthen small scale agricultural producers, like it has been done for large scale agricultural producers.

We need a shift from a technology-centered approach to one that focuses on socio-technical integrated systems. The future of digital agriculture should comprise of open digital infrastructure systems that enable the free movement of all kinds of data across various actors. Within such systems, mechanisms of data governance should be instituted. Above all, such systems should incorporate contextual Innovations for smallholder farmers to enable their sustainable economic activities (Artykmyradov et al., 2025; Priya et al., 2026).

### ***Limitations***

The limits of this research have been mentioned. First, the author only reviewed articles published in English. The review may have omitted relevant articles published in other languages and by other regional scientific councils. Second, because of the changing rate of technological development, the author acknowledges that this research may quickly become outdated. New innovations in Artificial Intelligence and quantum computing may transform agriculture. Finally, because of the limits of the current research, there is a lack of studies and information on the agricultural systems of less developed countries. The studies and information tend to be focused on the developed countries.

Fourth, the boundary between IoT data collection devices and AI software is blurring. As a result, categorizing technologies in digital agriculture is extremely difficult (Ahirwar et al., 2025; Vărzaru, 2025). As a narrative review, the approach here has been qualitative, and a critical assessment of the existing body of knowledge on digital agriculture has been

undertaken (Luff et al., 2021). While the authors' perspectives have been synthesized, the review has been structured, and methodological rules have been followed.

Based on the evidence integrated in this review, in digital agriculture, the optimization of agricultural production has more to do with the integration of various technologies (i.e. the interplay of several digital enablers and business model innovations) and the readiness of agricultural institutions, than it has to do with the integration of a single technology.

Digital tools and information infrastructure have the potential to optimize agricultural production. However, for the positive impacts of digital agriculture to be distributed broadly, improvements in the socio-political climate of the agricultural sector and related policy frameworks are also necessary. Investing in infrastructure and digital technologies and transforming the agricultural sector have to be integrated and aligned to achieve the desired impact.

---

**Acknowledgements:** The authors would like to express their sincere gratitude to Universiti Teknologi MARA Cawangan Kedah for providing the necessary resources and support throughout the course of this research. Special appreciation is extended to colleagues and peers who contributed valuable insights and constructive feedback, which greatly enhanced the quality of this paper.

**Funding Statement:** No funding.

**Conflict of Interest Statement:** The authors declare that there is no conflict of interest regarding the publication of this paper. All authors have contributed to this work and approved the final version of the manuscript for submission to the Advanced International Journal of Business, Entrepreneurship and SME's (AIJBES)

**Ethics Statement:** This study did not involve any human participants, animals, or sensitive data requiring ethical approval. The authors confirm that the research was conducted in accordance with accepted academic integrity and ethical publishing standards.

**Author Contribution Statement:** Ahmad Zulhafizi Shahril Annuar: conceptualization, literature search and screening, formal analysis, and writing of the original draft. Noor Zahirah Mohd Sidek: methodology, supervision, and writing (review and editing). Both authors read and approved the final version of the manuscript prior to submission.

**AI Declaration:** During the preparation of this work, the authors used generative AI tools to assist in graph and figure construction, and linguistic refinement of the narrative review. Following this process, the authors reviewed and edited the content as needed and take full responsibility for the academic integrity and final content of the publication.

---

## References

- Abdurakhmonova, F., & Orzikulov, M. (2025). The overview of digital technologies on agricultural productivity: Analysis of current trends. *Lecture Notes in Networks and Systems*, 1337, 294–303. [https://doi.org/10.1007/978-3-031-87532-8\\_26](https://doi.org/10.1007/978-3-031-87532-8_26)
- Adrian, A. M., Dillard, C., & Mask, P. (2004). GIS in agriculture. In *Geographic information systems in business* (pp. 324–342). IGI Global. <https://doi.org/10.4018/978-1-59140-399-9.ch015>
- Agrawal, K., & Kumar, N. (2025). AI-ML applications in agriculture and food processing. *Sustainable Development Goals Series, Part F102*, 21–37. [https://doi.org/10.1007/978-3-031-76758-6\\_2](https://doi.org/10.1007/978-3-031-76758-6_2)
- Ahirwar, S., Choubey, M., Gupta, Y. K., & Dubey, A. (2025). Digitization in smart farming: Revolutionizing agriculture. In *AgriTech revolution: Next-gen solutions and challenges in modern agriculture* (pp. 331–347). Springer. [https://doi.org/10.1007/978-981-95-1268-3\\_17](https://doi.org/10.1007/978-981-95-1268-3_17)
- Akimbekova, G., Espolov, T., Baimukhanov, A., Tazhibayeva, R., & Kontselidze, N. (2025). Digital transformation in agro-industrial complex: Technological innovations for sustainable development. *Lecture Notes in Mechanical Engineering*, 412–433. [https://doi.org/10.1007/978-3-031-94223-5\\_36](https://doi.org/10.1007/978-3-031-94223-5_36)
- Artykmyradov, B., Hojadurdyev, H., Babayev, I., Kivulya, D., Klukin, A., & Begmatov, I. (2025). Digital technologies in agriculture: Benefits and costs at different levels. *AIP Conference Proceedings*, 3256(1), Article 050033. <https://doi.org/10.1063/5.0267266>
- Babbar, S., Singhal, S., & Quraishi, S. J. (2025). Enhancing agricultural efficiency through the Internet of Things (IoT): Smart farming and precision agriculture. In *Precision and intelligence in agriculture: Advanced technologies for sustainable farming* (pp. 211–246). IGI Global. <https://doi.org/10.4018/979-8-3373-5283-1.ch008>
- Bhanu, A. N., Vaibhav, B., & Raj, S. (2026). Challenges and opportunities using AI toward crop improvement. In *Crop improvement with artificial intelligence: Methods and applications* (pp. 437–449). Wiley. <https://doi.org/10.1002/9781394330485.ch20>
- Bharat Babu, E., Ritvik, K., Sainath, L. V. A., & Tarun Sai, M. (2023). Blockchain-driven agricultural product traceability and supply chain management. In *Proceedings of the 5th International Conference on Inventive Research in Computing Applications (ICIRCA 2023)* (pp. 1202–1207). IEEE. <https://doi.org/10.1109/ICIRCA57980.2023.10220840>
- Bhardwaj, S., Venkatesan, S., Rawat, S., & Nath, P. (2024). Transforming agriculture with IoT for precision agriculture and sustainable crop management. In *The future of agriculture: IoT, AI and blockchain technology for sustainable farming* (pp. 164–200). Bentham Science Publishers. <https://doi.org/10.2174/9789815274349124010012>
- Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319–340. <https://doi.org/10.2307/249008>
- Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agriculture*, 12(10), Article 1745. <https://doi.org/10.3390/agriculture12101745>
- Dong, J., & Xu, J. (2026). Driving agricultural strength through digital transformation. *Scientific Reports*, 16(1), Article 446. <https://doi.org/10.1038/s41598-025-29878-3>
- Farzana Tasneem, M. I., & Achar, P. V. (2024). Journey to cyber-physical agricultural systems digitalization and technological evolution. In *Agri 4.0 and the future of cyber-physical*

- agricultural systems* (pp. 1–18). Elsevier. <https://doi.org/10.1016/B978-0-443-13185-1.00001-0>
- Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, 33(6–7), 897–920. <https://doi.org/10.1016/j.respol.2004.01.015>
- Green, B. N., Johnson, C. D., & Adams, A. (2006). Writing narrative literature reviews for peer-reviewed journals: Secrets of the trade. *Journal of Chiropractic Medicine*, 5(3), 101–117. [https://doi.org/10.1016/S0899-3467\(07\)60142-6](https://doi.org/10.1016/S0899-3467(07)60142-6)
- Hajiyeva, M. (2025). The application and role of digital technologies in the agrarian sector in modern times. *Scientific Work*, 19(4), 220–224. <https://doi.org/10.36719/2663-4619/114/220-224>
- Hiremath, G., & Hiremath, R. B. (2024). Transforming agri supply chains: A blockchain approach for quality assurance. In *Sustaining the global agriculture supply chain* (pp. 111–126). IGI Global. <https://doi.org/10.4018/979-8-3693-4330-2.ch004>
- Hossain, S., & Ghosh, D. (2026). Emerging digital technologies in agriculture: Innovations for a sustainable future. In *Digital twin technology for sustainable agriculture: Applications, implementation and future trends* (pp. 37–55). Springer. [https://doi.org/10.1007/978-981-95-5915-2\\_3](https://doi.org/10.1007/978-981-95-5915-2_3)
- Jiménez-López, F. R., Vera-Cely, O. F., & Jiménez-López, A. F. (2025). Transforming agriculture with the application of the Internet of Agricultural Things (IoAT). In *Proceedings of the LACCEI International Multi-Conference for Engineering, Education and Technology*. <https://doi.org/10.18687/LACCEI2025.1.1.1488>
- Kamal, S., & Saxena, S. (2026). Agriculture with IoT-enabled smart sensors: A new era of agriculture sustainability. *Smart Innovation, Systems and Technologies*, 467, 204–218. [https://doi.org/10.1007/978-3-032-12983-3\\_21](https://doi.org/10.1007/978-3-032-12983-3_21)
- Kamilaris, A., Kartakoullis, A., & Prenafeta-Boldú, F. X. (2017). A review on the practice of big data analysis in agriculture. *Computers and Electronics in Agriculture*, 143, 23–37. <https://doi.org/10.1016/j.compag.2017.09.037>
- Klerkx, L., Jakku, E., & Labarthe, P. (2019). A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. *NJAS - Wageningen Journal of Life Sciences*, 90–91, Article 100315. <https://doi.org/10.1016/j.njas.2019.100315>
- Kumar, V., & Sharma, S. (2025). Artificial intelligence and machine learning use in agriculture domain: A review. In *AI and ML techniques in image processing and object detection* (pp. 29–50). Springer. [https://doi.org/10.1007/978-981-96-7445-9\\_2](https://doi.org/10.1007/978-981-96-7445-9_2)
- Mrudula, D., Pandit, V. B., Ravali, C., Fiaz, S., Tariq, A., & Chatterjee, S. (2026). The role of GIS and GPS in modern agricultural practices. In *Artificial intelligence and data sciences for precision agriculture* (pp. 59–83). Springer. [https://doi.org/10.1007/978-3-032-12770-9\\_4](https://doi.org/10.1007/978-3-032-12770-9_4)
- Postolache, S., Sebastião, P., Viégas, V., & Postolache, O. (2025). Instrumentation and measurement systems: Digital twin for horticulture farm: Data source and data domain architecture. *IEEE Instrumentation & Measurement Magazine*, 28(4), 22–30. <https://doi.org/10.1109/MIM.2025.11021356>
- Priya, M. R., Rajan, R., Sathyanarayana, N., & Srikumar, M. S. S. V. (2026). Smart technologies for sustainable agriculture: Innovations and impacts within innovation ecosystems. In *Handbook on integrating smart technologies for sustainable development* (pp. 158–181). CRC Press. <https://doi.org/10.1201/9781003586951-10>
- Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

- Sankati, J., Bharti, P., Mishra, A. K., Durgam, V., Gakhar, S., & Sharma, S. (2025). Digital agriculture in South Asia: Innovations in farming for enhanced productivity. In *Transition to regenerative agriculture: Principles and indicators of soil health management* (pp. 111–140). Springer. [https://doi.org/10.1007/978-981-96-1421-9\\_6](https://doi.org/10.1007/978-981-96-1421-9_6)
- Sarma, S. S., Tholkapiyan, M., Shaik, N., Sundaram, A., Joshi, S., & Pathak, S. A. (2026). Remote sensing and GIS for precision agriculture: Enhancing crop monitoring and yield prediction. In *Computational techniques in precision agriculture: Advances and applications* (pp. 62–75). CRC Press. <https://doi.org/10.1201/9781003520733-6>
- Sharma, S., & Tyagi, R. (2023). Digitalization of farming knowledge using artificial intelligence and Vedic scripture. In *3rd IEEE International Conference on ICT in Business Industry and Government (ICTBIG 2023)*. IEEE. <https://doi.org/10.1109/ICTBIG59752.2023.10456219>
- Singh, G., & Veeramanickam, M. R. M. (2026). Applications of digital twins in agriculture: Enhancing crop monitoring, livestock health, soil fertility, and water management. In *Digital twin technology for sustainable agriculture: Applications, implementation and future trends* (pp. 295–307). Springer. [https://doi.org/10.1007/978-981-95-5915-2\\_16](https://doi.org/10.1007/978-981-95-5915-2_16)
- Singh, S., Singh, H. C., Gupta, P. K., Verma, A., & Verma, K. (2025). Embracing technological disruption: Digital tools for extension. In *Global horizons in agricultural extension education: Insights from international perspectives* (pp. 61–78).
- Singh, V., & Shukla, P. (2026). Introduction to Agriculture 5.0. In *Demystifying sustainable farming using smart technologies* (pp. 1–16). CRC Press. <https://doi.org/10.1201/9781779640932-1>
- Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 333–339. <https://doi.org/10.1016/j.jbusres.2019.07.039>
- Sravani, M., & Veeranjanyulu, N. (2025). A blockchain and IoT-driven framework for secure, transparent, and intelligent farm produce supply chains. In *2025 1st International Conference on Advancement in Futuristic Technologies (ICAFT 2025)*. IEEE. <https://doi.org/10.1109/ICAFT66710.2025.11452710>
- Ugwu, O. P.-C., Ogenyi, F. C., Alum, E. U., Eze, V. H. U., Basajja, M., Ugwu, J. N., Ugwu, C. N., Ejemot-Nwadiaro, R. I., Okon, M. B., Egba, S. I., & Ejim, U. D. (2025). Implementing artificial intelligence and machine learning algorithms for optimized crop management: A systematic review on data-driven approach to enhancing resource use and agricultural sustainability. *Cogent Food & Agriculture*, 11(1), Article 2569982. <https://doi.org/10.1080/23311932.2025.2569982>
- Värzaru, A. A. (2025). Digital revolution in agriculture: Using predictive models to enhance agricultural performance through digital technology. *Agriculture*, 15(3), Article 258. <https://doi.org/10.3390/agriculture15030258>
- Venable, C. (2008). Precision agricultural practices with GIS. *GEO: Connexion*, 7(5), 32–33.
- Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, 27(3), 425–478. <https://doi.org/10.2307/30036540>
- Vignesh, B., Chandrakumar, M., Divya, K., Prahadeeswaran, M., & Vanitha, G. (2025). Blockchain technology in agriculture: Ensuring transparency and traceability in the food supply chain. *Plant Science Today*, 12. <https://doi.org/10.14719/pst.5970>
- Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big Data in Smart Farming – A review. *Agricultural Systems*, 153, 69–80. <https://doi.org/10.1016/j.agsy.2017.01.023>
- World Bank. (2012). Agricultural innovation systems: An investment sourcebook. World Bank. <https://doi.org/10.1596/978-0-8213-8684-2>

- Zhang, H., & Zhu, H. (2025). The impact of agricultural digitization on land productivity: An empirical test based on micro panel data. *Land*, 14(1), Article 187. <https://doi.org/10.3390/land14010187>
- Zhang, N., Wang, M., & Wang, N. (2002). Precision agriculture – A worldwide overview. *Computers and Electronics in Agriculture*, 36(2–3), 113–132. [https://doi.org/10.1016/S0168-1699\(02\)00096-0](https://doi.org/10.1016/S0168-1699(02)00096-0)