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Digital Technologies in Agriculture: Transforming Farm Management and Agricultural Productivity

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Abstract

Digital technologies are rapidly transforming agriculture by enabling data-driven, precise, and efficient farm management. This review examines the role of emerging digital technologies, including the Internet of Things (IoT), sensor networks, remote sensing, drones, unmanned aerial vehicles (UAVs), big data analytics, artificial intelligence (AI), digital twins, and Farm Management Information Systems (FMIS), in improving agricultural productivity and sustainability. These technologies facilitate real-time monitoring of soil, crops, weather, water status, and pest and disease conditions, thereby supporting timely and informed farm-level decisions. Evidence indicates that digital agriculture can enhance crop productivity, optimize resource utilization, reduce waste, and lower greenhouse gas emissions and energy consumption. However, adoption remains uneven, particularly among smallholder farmers, due to high costs, fragmented landholdings, inadequate infrastructure, limited digital literacy, insufficient technical support, and weak policy frameworks. The review highlights the need for inclusive strategies combining technological innovation with infrastructure, financing, training, and supportive policies.

Keywords: *Digital agriculture; Precision farming; Internet of Things (IoT); Artificial intelligence; Agricultural productivity.*

1 Introduction

Modern agriculture faces mounting pressure from climate variability, resource scarcity, labour shortages, and a growing global population, compelling the sector to adopt digital solutions capable of enhancing efficiency and resilience. The agricultural sector needs to adapt to a host of mounting challenges, including climate change and broad environmental degradation, farmworker shortages, rising population levels and dietary transitions, and digital technologies are expected to be a major part of the solution to these challenges [1]. Digital agriculture, broadly defined, refers to the integration of modern data-monitoring tools and analytics into farming systems. Digital Agriculture is currently understood as using modern tools, data monitoring and analytics, and data-driven solutions in agriculture to improve and optimize farming systems, increase crop quality and yield, reduce waste, and manage pest and disease pressure [2]. This transformation has been accelerated by increases in computational power, faster internet and greater connectivity, declining technology costs, and the rise of big data paired with advanced analytics. Farmers can now access real-time, field-level information rather than relying solely on experience-based judgment, fundamentally reshaping how farm operations are planned and executed. This shift is particularly significant given that digital technologies provide agri-food producers with accurate and real-time observations regarding plant health, soil quality, weather conditions, and pest and disease pressure, enabling more informed and timely decisions across the production cycle [3], [4]. Against this backdrop, this review examines the core digital technologies reshaping farm management practices and evaluates their measurable impact on agricultural productivity, alongside the structural constraints that continue to limit widespread adoption, particularly among smallholder and resource-limited producers.

2 Core Digital Technologies Transforming Farm Management

The digitalisation of farm management is underpinned by a cluster of interrelated technologies that collectively enable data-driven decision-making across the production cycle. Each contributes a distinct capability, ranging from real-time field monitoring to predictive analytics and virtual simulation of farm systems [5].

- **IoT and Sensor Networks:** These tools allow farmers to obtain real-time data on crops, assessing key health factors such as soil conditions, plant water status, and presence of pests, resulting in data-based decision-making to optimize irrigation, fertilization, and pest control.
- **Remote Sensing, Drones and UAVs:** Aerial monitoring tools increase monitoring capabilities through comprehensive field surveys, supplementing ground-based sensor data with spatial crop health mapping.
- **Big Data and Artificial Intelligence:** Big data analytics and AI are crucial in analyzing extensive datasets to uncover patterns and trends and provide valuable insights for improving agricultural practices.
- **Digital Twins and Farm Management Information Systems (FMIS):** A virtual replica of the crop, including irrigation, fertilization strategy, and pest management, can support decision-making and a step change in farm management.

3 Impact on Productivity and Adoption Constraints

The adoption of digital agricultural technologies has produced measurable productivity and sustainability gains, though these benefits remain unevenly distributed across farm types. Real-time monitoring technologies have been instrumental in driving yield increases across various agricultural sectors by enabling more informed and precise farm management decisions, while integrated IoT and AI-driven precision systems have demonstrated notable environmental gains, including a 20% drop in CO_2 emissions and, in EU-funded precision cropping initiatives, a 10% reduction in GHG emissions alongside a 5% decrease in energy usage [6]. However, these gains are not uniformly realised, as adoption remains constrained by structural and economic barriers. The five main constraints of precision agriculture technologies at the small-scale level are small land size, high cost of adoption, technology-related difficulties, lack of professional support, and lack of supporting policy. Consequently, a gap persists between the desired diffusion of digital technologies, actual adoption rates in farming practices, and the potential benefits these technologies offer for sustainable smallholder agriculture. This disparity underscores that technological capability alone is insufficient; complementary investment in infrastructure, extension support, and financing mechanisms is required to translate digital innovation into broad-based productivity gains [7].

4 Literature review

(Junior et al., 2024) [8] Digitalisation is rapidly transforming agricultural practices worldwide, offering immense potential for smallholder farmers in sub-Saharan Africa (SSA). Analyzing 27 studies, this review explores current digital tools, such as digital extension services and e-marketing, which successfully enhance information access, market reach, and productivity. However, widespread adoption is severely constrained by barriers including limited internet connectivity, low digital literacy, inadequate infrastructure, affordability issues, and gender disparities. Despite these hurdles, digital tools create critical opportunities for improved decision-making, higher incomes, and uplifted livelihoods. Overcoming structural barriers through targeted interventions is essential for harnessing digitalization to drive sustainable agricultural growth across sub-Saharan Africa.

(Ashokkumar & Naik, 2021)[9] Agriculture remains a vital component of the Indian economy, yet millions of farmers face persistent challenges like low yields, inconsistent product quality, and poor access to diversified agricultural and market information. Farmers urgently require timely, location-specific data in their local languages throughout all cultivation stages. Adopting digital communication and mobile technologies enhances information transmission speed and farmer participation at the grassroots level. Government initiatives such as Digital Green, e-Choupal, agricultural drones, and precision farming are pivotal at this critical juncture. Promoting these digital efforts on a large scale helps bridge knowledge gaps, improve crop management practices, and empower farmers to overcome economic and informational bottlenecks.

(Du et al., 2022) [10] The purpose of this paper is to show the impact of digital agriculture on food supply chain, research trend, emphasis and implications for future research. The paper analyzes how the digital technology reshapes the production, assembly, transaction, retail and logistics. Impact from each main technological progress is discussed. First, digital agriculture develops quickly and changes all parts of the food supply chain. Second, while many technological progresses show their impacts in agriculture and food sector, e-commerce and progress of artificial intelligence show its comprehensive impact on the argi-food sector. The paper shows the technological trend and progress in food and agriculture sector. Researchers focusing on agricultural economics and agribusiness should pay attention to recent developments in the real world, know the recent developments from other disciplines, get more data for empirical research and show the impact of digital agriculture on consumer's preference and social welfare.

(Sermuksnyte-alesiuniene & Ispiryan, 2026) [11] Addressing the critical global challenge of uneven digital technology adoption, this study investigates how digital tools enhance sustainability metrics, resource efficiency, and renewable energy integration within the bioeconomy. Using a mixed-methods design combining quantitative indicators and regional socio-economic assessments, the research applies regression models to analyze digital adoption outcomes. Results reveal that regions with high technological adoption, such as Europe and North America, exhibit significant sustainability advancements, whereas Asia and Africa show modest improvements. The findings emphasize the urgent need for region-specific strategies, infrastructural investments, and technological parity to leverage digital innovations effectively for climate resilience and global food security.

(Fuentes-peñailillo et al., 2024) [12] This paper explores the potential of smart crop management through tools like the Internet of Things (IoT), remote sensing, and artificial intelligence (AI) to enhance resource efficiency amid varying climatic conditions. IoT sensor networks provide farmers with real-time data on soil conditions, plant water status, and pest presence, enabling data-driven optimization of irrigation and fertilization. Furthermore, drones and unmanned aerial vehicles (UAVs) expand monitoring capabilities for high-precision growth tracking, while big data analytics uncover essential trends. Addressing global adoption barriers, the review underscores the critical necessity for ongoing research and collaborative efforts to achieve sustainable and highly efficient crop production systems.

(Singh et al., 2026) [13] Integrating digital agriculture and smart farming provides revolutionary solutions to global food security, climate change, and resource depletion. Reviewing innovations like IoT, AI, UAVs, and blockchain, the paper details how transitioning to data-centric methodologies optimizes staple crop management. Nevertheless, global diffusion remains heavily uneven. Focusing on the Indian context dominated by smallholders with fragmented landholdings, the transition faces severe economic constraints, poor digital infrastructure, digital illiteracy, and a lack of standardized data governance. Synthesizing current literature, the review highlights critical bottlenecks and stresses the urgent need for cohesive policy interventions and localized platforms to accelerate inclusive digital adoption in developing economies.

5 Conclusion

Digital technologies are fundamentally reshaping farm management by shifting agricultural decision-making from conventional experience-based approaches toward data-driven and precision-oriented practices. Technologies such as IoT and sensor networks, remote sensing, UAVs, AI, big data analytics, digital twins, and Farm Management Information Systems provide timely information that can improve crop monitoring, irrigation, fertilization, pest management, resource efficiency, and overall productivity. Evidence reviewed in this study demonstrates that digital agriculture can contribute not only to higher and more stable production but also to reduced energy use, greenhouse gas emissions, and agricultural waste. Nevertheless, the benefits of digitalisation remain uneven because adoption is constrained by high technology costs, fragmented and small landholdings, inadequate digital infrastructure, limited digital literacy, insufficient professional support, and policy gaps. Therefore, achieving inclusive digital transformation requires coordinated investments in connectivity, farmer training, affordable technologies, extension services, financing, and enabling policy frameworks. Such integrated approaches can strengthen the contribution of digital agriculture to sustainable, productive, and climate-resilient farming systems.

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