CHAPTER-18

USE OF DIGITALIZATION FOR SUSTAINABLE AGRICULTURE VALUE CHAIN

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Cite this chapter as: Chavan, V. Use of Digitalization for Sustainable Agriculture Value Chain. In: Bhat, A., A. Sultan, D. Kolhe & P. Banerjee. 2026 Digital Agriculture and Economic Transformation. The AgEcon Frontiers, Faisalabad, Pakistan, pp: 264-267. https://doi.org/10.66529/book.9786277945022.2026.ch18
A Publication of The AgEcon Frontiers Received: 26-May-2026 Revised: 05-June-2026 Accepted: 07-June-2026

Abstract

The agricultural sector is undergoing a transformative shift toward Agriculture 4.0, driven by the urgent need to address global population growth and climate change. This chapter explores the integration of digitalization within the sustainable agriculture value chain, highlighting how data-driven insights optimize resource use and enhance economic viability. Key technological drivers discussed include the Internet of Things (IoT) for real-time field monitoring, Artificial Intelligence (AI) for predictive analytics, and Precision Agriculture techniques like Variable Rate Technology (VRT) to minimize environmental impact. Furthermore, the roles of drones, robotics, and blockchain are examined for their contributions to automation and supply chain transparency. The concept of Digital Twins and Industry 5.0 are introduced as frameworks for balancing machine efficiency with human intuition. Finally, the chapter addresses the empowerment of smallholder farmers through mobile applications while acknowledging systemic challenges such as the digital divide and high initial costs. The findings suggest that a collaborative, global digital framework is essential for a resilient and food-secure future.

Keywords: Agriculture 4.0, IoT, Precision Agriculture, Artificial Intelligence, Sustainable Value Chain.

1. Introduction to Digitalization in Agriculture

The agricultural sector is at the precipice of a fourth industrial revolution, often termed 'Agriculture 4.0'. As global populations rise and climate change threatens traditional farming cycles, the 'Use of Digitalization for Sustainable Agriculture Value Chain' becomes not just an innovation, but a necessity. Digitalization refers to the integration of digital technologies into agricultural processes to transform the way food is produced, processed, and distributed. By leveraging data-driven insights, farmers can optimize resource use, minimize environmental footprints, and enhance the economic viability of their operations (FAO, 2020; Lajoie-O'Malley et al., 2020).

At the core of digital agriculture lies the Internet of Things (IoT). IoT involves a network of sensors and devices that collect real-time data from the field ranging from soil moisture and ambient temperature to livestock health. Machine-to-Machine (M2M) communication allows these devices to interact seamlessly, ensuring that irrigation pumps or fertilization systems react instantly to changing conditions without human intervention. This connectivity is supported by diverse infrastructures like 5G for high-speed data and LoRaWAN for long-range, low-power sensor deployments (Khanna & Kaur, 2019).

3. Artificial Intelligence: The Cognitive Engine

Artificial Intelligence (AI) and Machine Learning (ML) act as the brain of the digital farm. These technologies process the massive volumes of 'Big Data' generated by sensors. ML algorithms can identify patterns in crop growth, predict yield with high accuracy, and detect early signs of pest infestations through image recognition. Deep Learning models, specifically Convolutional Neural Networks (CNNs), are now used to analyze satellite and drone imagery to distinguish between weeds and crops, allowing for targeted herbicide application (Zhai et al., 2020; Javaid et al., 2022).

4. Precision Agriculture and Resource Sustainability

Sustainability in the value chain is achieved through Precision Agriculture. This approach ensures that agricultural inputs water, fertilizer, and pesticides are applied with surgical precision. Smart irrigation systems utilize soil sensors and weather forecasts to prevent over-watering, saving up to 30% of water resources. Similarly, Variable Rate Technology (VRT) allows machinery to adjust the amount of fertilizer applied based on the specific needs of a patch of soil, preventing nitrogen runoff into local water bodies (Khanna & Kaur, 2019; Zhai et al., 2020).

5. Drones and Robotics: Automating the Future

Unmanned Aerial Vehicles (UAVs) or drones have revolutionized field mapping and crop scouting. Equipped with multispectral sensors, drones can provide high-resolution data on plant vigor. Furthermore, agricultural robots (agribots) are increasingly handling labor-intensive tasks such as fruit picking, weeding, and planting. These robots work tirelessly and with a level of precision that reduces waste and human error, significantly lowering the overall carbon footprint of farm operations (Tagarakis & Bochtis, 2023).

6. Blockchain for Traceability and Transparency

Sustainable value chains require transparency. Blockchain technology provides an immutable ledger that tracks a product's journey from the farm to the consumer's plate. Each step harvesting, processing, and shipping is recorded, ensuring food safety and building consumer trust. This traceability is crucial for organic certification and fair-trade verification, ensuring that sustainable practices are rewarded in the marketplace (Rejeb et al., 2020).

7. Digital Twins and Industry 5.0

The concept of the 'Digital Twin' involves creating a virtual replica of a physical farm. By running simulations on the twin, farmers can predict the outcome of different planting strategies or climate scenarios before committing resources. Industry 5.0 brings the human element back into focus, emphasizing the collaboration between human intuition and machine efficiency to ensure that technology serves the well-being of the farmer and the environment alike (Verma, 2024).

8. Smart Apps and Farmer Empowerment

Mobile applications like 'SmartKheti' bridge the information gap for smallholder farmers. These apps provide localized weather alerts, market prices (Mandis), and crop-specific advice. By democratizing access to information, digital tools empower farmers to participate more effectively in the value chain, reducing the influence of middlemen and increasing profit margins (Kamal & Bablu, 2023).

9. Challenges and the Path to Scaling

Despite the benefits, challenges such as high initial costs, the digital divide in rural areas, and data privacy concerns remain. To achieve a truly sustainable value chain, there is a need for standardized communication protocols and government-backed initiatives to provide affordable technology to small-scale farmers. International cooperation is essential to create a global framework for digital agriculture (FAO, 2020; Lajoie-O'Malley et al., 2020).

10. Conclusion: A Greener Future

The digitalization of agriculture is the key to balancing productivity with planet health. By integrating AI, IoT, and robotics, the agricultural value chain becomes more resilient, efficient, and transparent. As these technologies mature and become more accessible, they will pave the way for a sustainable future where agriculture can feed the world without depleting its natural resources (Javaid et al., 2022).

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Declaration: AI-assisted tools (LLMs) were used to improve the language and grammar of this chapter. The authors reviewed and approved all content and assume full responsibility for its accuracy.