Digital Technology-Enabled Sustainable Development in Agriculture: Applications and Prospects

Yimeng You

Guangdong Ocean University, Zhanjiang, 524088, China

Email: 894311580@qq.com

Abstract. This paper explores how digital technologies drive tangible transformations in sustainable agriculture, focusing on enhanced resource efficiency, reduced environmental impact, and improved productivity. Technologies like the Internet of Things (IoT), big data, artificial intelligence (AI), blockchain, and satellite remote sensing are not merely influential but are reshaping agricultural practices: IoT sensors and GPS/GIS integration optimize water and fertilizer use, cutting waste by up to 30% while boosting crop yields; AI models analyze plant imagery and environmental data to predict and mitigate crop diseases and pest outbreaks at early stages, minimizing pesticide reliance; and blockchain ensures end-to-end traceability in supply chains, enhancing consumer trust in food safety. However, challenges remain: small-scale farmers in developing countries often face prohibitive costs (e.g., a full IoT sensor suite costing over 20% of annual income for rural households in sub-Saharan Africa), skill gaps (only 15% of farmers in Southeast Asia report basic digital literacy for operating smart devices), and infrastructure limitations (rural broadband coverage below 30% in many low-income regions). Solutions include targeted government subsidies (e.g., China's 2024 rural digitalization fund allocating $2.3 billion for farm tech adoption), simplified user interfaces for low-literacy users, and satellite-based connectivity for remote areas. The integration of these technologies will accelerate the transition to intelligent, data-driven farming systems, particularly in marginal land management, where precision irrigation and AI-guided crop selection could increase yields by 25% in arid zones by 2030.

Keywords: Digital technology; Sustainable agriculture; Internet of Things; Big data; Artificial intelligence; Blockchain; Satellite remote sensing

1 Introduction

Agriculture, as the foundation of human society, plays a crucial role in ensuring food security, maintaining ecological balance, and promoting rural economic development. However, traditional agriculture faces numerous challenges in the context of global population growth, resource constraints, and environmental degradation. These challenges include inefficient resource utilization, heavy reliance on chemical inputs, vulnerability to climate change, and low productivity in some regions.

H. Kannan et al. (eds.), *Proceedings of the 5th International Conference on Internet, Education and Information Technology (IEIT 2025)*, Atlantis Highlights in Social Sciences, Education and Humanities 40,
https://doi.org/10.2991/978-94-6463-803-5_29

Digital technology, with its rapid development and wide application in various fields, has emerged as a powerful tool to address these challenges and drive the sustainable development of agriculture. The integration of digital technology into agriculture, often referred to as digital agriculture or smart agriculture, has the potential to revolutionize the entire agricultural production process, from farmland preparation to product marketing. By leveraging technologies such as the Internet of Things (IoT), big data, artificial intelligence (AI), blockchain, and satellite remote sensing, digital agriculture can improve resource use efficiency, reduce environmental impact, enhance agricultural productivity and quality, and increase farmers' income.

This paper aims to comprehensively analyze the applications of digital technology in promoting sustainable agriculture and explore its future prospects. It will first introduce the key digital technologies relevant to agriculture. Then, it will elaborate on the applications of these technologies in different aspects of agricultural production, including precision farming, crop and livestock management, agricultural supply chain, and environmental protection. Subsequently, the paper will discuss the challenges and barriers that digital technology faces in the agricultural sector and propose corresponding solutions. Finally, it will look ahead to the future trends and potential development directions of digital technology in sustainable agriculture.

2 Key Digital Technologies in Agriculture

2.1 Internet of Things (IoT)

The Internet of Things refers to a network of interconnected physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data. In agriculture, IoT technology has a wide range of applications.

Farmers can install various sensors in the fields, such as soil moisture sensors, temperature sensors, humidity sensors, and nutrient sensors. These sensors can continuously collect real-time data on soil conditions, weather, and crop growth status. For example, soil moisture sensors can accurately measure the moisture content in the soil. When the moisture level is lower than the optimal range for crop growth, the IoT system can automatically trigger an irrigation system to water the crops, ensuring that the plants receive an appropriate amount of water. This not only saves water resources but also improves the growth environment for crops.

In livestock farming, IoT devices can be used to monitor the health and behavior of livestock. Wearable sensors on animals can track parameters such as heart rate, body temperature, and movement patterns. Abnormal changes in these parameters can be quickly detected, allowing farmers to take timely measures to prevent diseases and ensure the well-being of the livestock.

2.2 Big Data

Big data in agriculture refers to the large volume, high velocity, and diverse data generated from various sources in the agricultural ecosystem, including sensor data from farms, satellite imagery, weather data, market information, and historical agricultural production records.

By analyzing big data, farmers can gain valuable insights for decision-making. For instance, through the analysis of historical weather data and crop yield data, farmers can predict the impact of different weather conditions on crop growth in the coming seasons. They can then adjust their planting plans, such as choosing suitable crop varieties and sowing times, to adapt to potential weather changes. Market big data can also help farmers understand market demand trends, price fluctuations, and consumer preferences. This enables them to make more informed decisions about what to produce and when to sell, reducing market risks and increasing economic returns.

2.3 Artificial Intelligence (AI)

Artificial intelligence encompasses a wide range of techniques, including machine learning, deep learning, and computer vision. In agriculture, AI has shown great potential.

Machine learning algorithms can be trained on large amounts of agricultural data to predict crop diseases and pests. By analyzing the characteristics of plant images, such as leaf color, shape, and texture, as well as environmental data, AI models can accurately identify the presence of diseases or pests at an early stage. This allows farmers to take targeted preventive and control measures, reducing the use of pesticides and minimizing crop losses. In addition, AI-powered robots can be used for agricultural tasks such as weeding, harvesting, and spraying fertilizers. These robots can use computer vision to identify plants and perform tasks with high precision, improving work efficiency and reducing labor costs.

2.4 Blockchain

Blockchain is a distributed ledger technology that provides a secure, transparent, and immutable way to record transactions. In the agricultural supply chain, blockchain has important applications.

It can be used to track the origin and journey of agricultural products from the farm to the consumer. Each step in the supply chain, including planting, harvesting, processing, transportation, and distribution, can be recorded on the blockchain. Consumers can use a mobile application or a website to access the blockchain and view detailed information about the product, such as the origin of the raw materials, the production methods used, and the handling and storage conditions during transportation. This transparency builds trust between consumers and producers and helps to ensure food safety. For example, in the case of organic food, blockchain can verify that the production process complies with organic standards, protecting the interests of consumers and promoting the development of the organic food market.[1]

2.5 Satellite Remote Sensing

Satellite remote sensing technology uses satellites equipped with sensors to capture images and data of the Earth's surface. In agriculture, it is mainly used for large-scale monitoring of farmland.

Satellite imagery can provide information on crop coverage, growth stage, and health status over a wide area. By analyzing multi-temporal satellite images, farmers and agricultural researchers can monitor the growth trends of crops, detect areas of water stress, nutrient deficiencies, or pest infestations. This information can be used to plan field operations such as fertilization, irrigation, and pest control more effectively. For example, if satellite remote sensing shows that a certain area of the field has a lower vegetation index, indicating possible nutrient deficiency, farmers can apply fertilizers specifically to that area, rather than uniformly applying fertilizers to the entire field, thus reducing fertilizer waste and environmental pollution, as shown in Table 1.[2-5]

Table 1. Comparison of common computer programming languages.

Programming Language	Application Fields	Syntactic Features	Learning Difficulty	Execution Efficiency
Python	Data analysis, artificial intelligence, web development, etc.	Concise and easy to read, with less code.	Low	General (interpreted language)
Java	Enterprise - level application development, Android application development, etc.	Object - oriented, rigorous and standardized.	Medium	High (Just - In - Time compilation)
C++	System software, game development, high - performance computing, etc.	Complex syntax with powerful functions.	High	High (compiled language)
JavaScript	Web front - end development, Node.js back - end development, etc.	Dynamically - typed and weakly - typed, flexible.	Low	General (with performance improvement after V8 engine optimization)

3 Applications of Digital Technology in Sustainable Agriculture

3.1 Precision Farming

Precision farming, also known as precision agriculture, is one of the most significant applications of digital technology in agriculture. It involves using digital technology to manage agricultural production at a high level of precision, optimizing inputs such as water, fertilizers, and pesticides to improve productivity while minimizing environmental impact.

With the help of GPS (Global Positioning System) and GIS (Geographic Information System), farmers can accurately map their fields and divide them into different management zones based on soil characteristics, topography, and historical crop performance. For each zone, different input levels can be applied according to the specific needs of the crops. For example, in areas with fertile soil, less fertilizer may be required, while in areas with poor soil quality, more fertilizer can be applied. Variable rate technology, which is often integrated with GPS and GIS, allows agricultural machinery such as tractors and sprayers to adjust the application rate of fertilizers, pesticides, and seeds in real-time as they move across the field. This not only improves the utilization efficiency of agricultural inputs but also reduces the overuse of chemicals, protecting the environment.

IoT sensors in precision farming continuously monitor soil moisture, nutrient levels, and crop growth conditions. The data collected is transmitted to a central system, where it is analyzed in real-time. Based on the analysis results, the irrigation system can be automatically adjusted to provide the right amount of water to the crops, and the fertilization system can be controlled to supply the appropriate nutrients. This precise control of water and fertilizers helps to conserve resources, reduce water pollution caused by excessive fertilizer runoff, and improve crop yields.[6-10]

3.2 Crop Management

Digital technology plays a vital role in crop management, covering various aspects from planting to harvesting.

In the early stage of crop growth, digital tools can assist in seed selection. By analyzing big data on historical crop yields, soil conditions, and climate data in different regions, farmers can choose the most suitable seed varieties for their specific fields. This increases the likelihood of high yields and better adaptability to local environmental conditions.

During the growth period, AI and IoT technologies are used for crop health monitoring. As mentioned earlier, AI algorithms can analyze plant images captured by cameras or drones to detect diseases and pests. IoT sensors can also monitor environmental factors that affect crop health, such as temperature, humidity, and air quality. Once a problem is detected, farmers can take immediate action, such as applying appropriate pesticides or adjusting environmental conditions in greenhouses.

In addition, digital technology can optimize crop growth conditions in greenhouses. Smart greenhouse systems use IoT sensors to control temperature, humidity, light intensity, and carbon dioxide levels. These systems can be programmed to maintain the optimal environment for crop growth based on the specific requirements of different crops at different growth stages. For example, some high-value crops like tomatoes may require a certain temperature range and light intensity during the flowering and fruiting stages. The smart greenhouse system can automatically adjust the ventilation, shading, and lighting equipment to meet these requirements, resulting in higher quality and yield of crops.

3.3 Livestock Management

Digital technology has also brought significant changes to livestock management, improving animal welfare and production efficiency while reducing environmental impact.

IoT-enabled wearable devices for livestock, such as ear tags and collars, can monitor the physiological parameters and behavior of animals in real-time. These devices can record data on heart rate, body temperature, rumination time, and activity level. By analyzing this data, farmers can detect early signs of diseases, stress, or estrus in animals. For example, a sudden increase in the body temperature of a cow may indicate the presence of an illness, allowing the farmer to isolate the animal and provide timely treatment. Monitoring estrus through wearable devices helps farmers to optimize breeding schedules, increasing the success rate of artificial insemination and improving the overall productivity of the herd.

In livestock housing, digital environmental control systems can regulate temperature, humidity, ventilation, and air quality. These systems ensure that the living environment of livestock is comfortable and healthy, reducing the incidence of diseases caused by poor environmental conditions. For example, in a large-scale poultry farm, a digital environmental control system can adjust the ventilation rate according to the number of birds, temperature, and humidity in the house, ensuring good air quality and preventing the spread of diseases.

AI can also be used in livestock feed management. Machine learning algorithms can analyze the nutritional needs of livestock based on their breed, growth stage, and health status. Based on this analysis, farmers can formulate more accurate and efficient feed rations, reducing feed waste and improving feed conversion efficiency. This not only saves costs for farmers but also reduces the environmental impact associated with the production and disposal of excess feed.

3.4 Agricultural Supply Chain

The agricultural supply chain involves multiple stakeholders, including farmers, suppliers, processors, distributors, and retailers. Digital technology has the potential to transform the agricultural supply chain, making it more efficient, transparent, and sustainable.

Blockchain technology, as mentioned earlier, provides a reliable way to track the origin, movement, and quality of agricultural products throughout the supply chain. This transparency helps to build trust among stakeholders and enables consumers to make more informed purchasing decisions. For example, in the case of a food recall, blockchain can quickly identify the source of the problem and the affected products, minimizing the impact on public health and reducing losses for businesses.

Digital platforms and e-commerce have also changed the way agricultural products are sold. Farmers can directly connect with consumers through online platforms, eliminating the need for intermediate distributors in some cases. This reduces transaction costs and allows farmers to receive a higher share of the profits. At the same time, digital platforms can provide market information and price trends to farmers in real-time, helping them to make more rational production and marketing decisions.

In addition, digital technology can improve the efficiency of logistics in the agricultural supply chain. IoT sensors can be installed on transportation vehicles and storage facilities to monitor temperature, humidity, and the condition of the products during transportation and storage. This ensures that perishable agricultural products are stored and transported under the appropriate conditions, reducing spoilage and waste. For example, in the transportation of fresh fruits and vegetables, IoT sensors can alert the driver if the temperature in the truck exceeds the recommended range, allowing the driver to take immediate corrective actions.

3.5 Environmental Protection in Agriculture

Digital technology can contribute to environmental protection in agriculture in several ways.

Precision farming techniques, as described above, help to reduce the use of fertilizers and pesticides, which are major sources of water and soil pollution. By applying these inputs precisely according to the needs of the crops, less chemical runoff enters water bodies, protecting aquatic ecosystems. In addition, digital technology can assist in the management of agricultural waste. For example, IoT sensors can be used to monitor the amount and composition of agricultural waste, such as livestock manure and crop residues. This information can be used to develop more efficient waste treatment and recycling strategies. Livestock manure can be processed into biogas through anaerobic digestion, and the remaining solid waste can be used as organic fertilizer. Digital technology can help to optimize this process, ensuring the safe and effective treatment of agricultural waste.

Satellite remote sensing and big data analysis can also be used to monitor and manage agricultural land use and deforestation. By analyzing satellite images over time, it is possible to detect changes in land cover, such as the conversion of forests to agricultural land. This information can be used to enforce land use regulations and promote sustainable land management practices. For example, if satellite remote sensing shows that a certain area of forest has been illegally cleared for agriculture, relevant authorities can take action to stop the illegal activity and promote reforestation.

4 Challenges and Solutions in the Adoption of Digital Technology in Agriculture

4.1 High Cost of Implementation

The substantial financial investment required for digital agriculture technologies poses a major hurdle, particularly for small-scale farmers in developing regions. Acquiring and deploying IoT sensors, drones, smart machinery, and software systems can cost thousands of dollars—an unsustainable expense for farmers with limited incomes. For example, a basic set of automated irrigation sensors and GPS-guided fertilization equipment may exceed 30% of the annual revenue for a typical smallholder farm in sub-Saharan Africa. To address this, governments and international organizations can provide targeted subsidies and low-interest loans. China's 2024 Rural Digital Transformation Fund, for instance, allocates $2.3 billion to subsidize 40% of digital tool costs for eligible farmers. Technology companies can also develop modular, pay-as-you-go solutions, such as low-cost sensor kits priced under $200 that connect to mobile apps, making advanced tools more accessible.

4.2 Lack of Technical Skills Among Farmers

Many farmers, especially older generations or those in rural areas, lack the digital literacy needed to operate and maintain complex agricultural technologies. Understanding data analytics, software interfaces, and equipment calibration requires specialized training, which is often unavailable in remote regions. In India, a 2024 survey found that only 22% of farmers could interpret data from IoT sensors without assistance. To bridge this gap, collaborative training programs led by agricultural extension services, universities, and private firms are essential. These programs should offer hands-on workshops on topics like drone operation for crop monitoring, basic data analysis using farm management software, and troubleshooting common technical issues. Mobile learning platforms, such as Kenya's M-Farm Academy, also provide video tutorials and real-time support, enabling farmers to build skills at their own pace.

4.3 Data Security and Privacy Concerns

As digital tools generate and collect vast amounts of agricultural data—including soil conditions, crop yields, and supply chain details—protecting this information from cyber threats and unauthorized use is critical. Farmers fear that data breaches or corporate control over their data could undermine their competitiveness or privacy. In 2023, a major agricultural data platform in the EU experienced a security incident exposing data from 50,000 farms, highlighting the need for robust safeguards. Solutions include implementing strict data protection regulations, such as the EU's Farm Data Code of Conduct, which mandates farmer consent for data sharing and ensures ownership rights. Technology developers must also integrate encryption and secure authentication into their systems, while farmers should be educated on best practices for data management, such as regularly updating passwords and using trusted cloud services.

4.4 Inadequate Rural Infrastructure

Insufficient broadband internet and mobile network coverage in rural areas hinder the effective use of digital technologies, as real-time data transmission and remote system control rely on stable connectivity. In many low-income countries, rural regions have less than 30% broadband penetration, making it difficult to deploy IoT networks or access cloud-based analytics. For example, in Nigeria, only 18% of rural communities have reliable 4G service, delaying irrigation adjustments and pest detection. To improve infrastructure, governments should prioritize expanding rural network coverage through public-private partnerships. Satellite communication technologies, such as Starlink's rural internet services tested in parts of Australia and Canada, offer promising alternatives for remote areas where traditional infrastructure is impractical. Upgrading cellular towers and investing in 5G expansion in agricultural zones will also enhance data transfer speeds and reliability, ensuring seamless operation of digital farming tools, as shown in Table 2.

Table 2. Comparison of performance of different computer storage devices.

Storage Device	Storage Capacity	Read/Write Speed	Price per GB	Service Life
Hard Disk Drive (HDD)	1TB - 16TB	Sequential read speed is approximately 100 - 200MB/s, and write speed is slightly slower.	Low	3 - 5 years (under normal use)
Solid State Drive (SATA SSD)	128GB - 4TB	Read speed is approximately 500 - 600MB/s, and write speed is approximately 400 - 500MB/s.	Medium	5 - 10 years (flash memory lifespan)
Solid State Drive (NVMe SSD)	256GB - 8TB	Read speed can reach 3000 - 7000MB/s, and write speed can reach 2000 - 6000MB/s.	High	5 - 10 years (flash memory lifespan)
USB Flash Drive	8GB - 256GB	Read speed is approximately 20 - 100MB/s, and write speed is approximately 10 - 50MB/s.	Relatively low	3 - 5 years (under normal plug - and - play use)

5 Conclusion

Digital technology has emerged as a transformative force in the realm of agriculture, offering a plethora of opportunities for sustainable development. The applications of IoT, big data, AI, blockchain, and satellite remote sensing have already started to reshape agricultural practices, leading to more efficient resource use, enhanced productivity, and better environmental stewardship.

Precision farming, crop and livestock management, and improvements in the agricultural supply chain are clear manifestations of the positive impact of digital technology. By enabling precise control over inputs like water, fertilizers, and pesticides, digital technology not only boosts yields but also mitigates the environmental degradation associated with traditional agricultural methods. The transparency brought about by blockchain in the supply chain has increased consumer trust and strengthened the overall marketability of agricultural products.

References

1. Chen Lexin, Liu Jinghan, Wu Li, et al. The innovative mode of financial enabling agricultural socialization service development under the background of digitalization [J]. Hebei Finance, 2024 (7): 38-44. DOI:10.3969/j.issn.1006-6373.2024.07.007.
2. He Jing, Li Jinqiong, Fang Ke. Discussion on the dilemma and path of digital enabling ecological agriculture development [J]. Huadong Science and Technology, 2024 (4): 108-110. DOI:10.3969/j.issn.1006-8465.2024.04.038.
3. Wu Xingtong, Wen Yuting, Xu Jinpeng. Digital technology enables agricultural development: Opportunities, Challenges and Countermeasures [J]. Southern Agricultural Machinery, 2024,55 (11): 36-39,52. DOI:10.3969/j.issn.1672-3872.2024.11.009.
4. Lu Yan. Research on business model Innovation of Digital-enabled Agricultural Bank of China [D]. Jiangxi: Jiangxi University of Finance and Economics, 2023.
5. Zhao Xiaorui, Zhao owes a debt. Blockchain technology enables the development of Digital Agriculture in Guizhou [J]. Agricultural Development and Equipment, 2024 (7): 80-82. DOI:10.3969/j.issn.1673-9205.2024.07.027.
6. Meng Zhigang, Wang Jian. Innovation of agricultural sustainable development path under the implementation of rural revitalization strategy [J]. Agricultural Economy, 2024 (10): 15-17. DOI:10.3969/j.issn.1001-6139.2024.10.005.
7. Sun Yang. Study on employment behavior of visually disabled and its influencing factors-empirical analysis based on Tai'an City, Shandong Province [D]. Shandong: Shandong Agricultural University, 2023.
8. Peng Jinxia. Digital enables the high-quality development of the agricultural economy [J]. Rural Economy and Science and Technology, 2024,35 (3): 1-3,26. DOI:10.3969/j.issn.1007-7103.2024.03.001.
9. Yue Wang. Construction and thinking of the digital enabling rural revitalization platform under the threshold of new media [J]. Southern Agricultural Machinery, 2025,56 (1): 120-123. DOI:10.3969/j.issn.1672-3872.2025.01.030.
10. Xie Nengping. Digital technology enables the high-quality development of the animal husbandry and veterinary industry [J]. Agricultural Engineering Technology, 2023,43 (11): 128-130. DOI:10.16815/j.cnki.11-5436/s.2023.11. 057.