

Digital Agriculture Practices and Innovative Product Development Strategies

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Abstract. In recent years, digitization in the agricultural sector has made production processes more efficient, sustainable, and traceable. Tools such as IoT-based sensors, AI-powered decision support systems, UAV, and satellite technologies play an important role in the digital transformation of agriculture. This study examines the implementation of digital agriculture technologies, their impact on the sector, and innovative product development strategies. Case studies of digital agriculture applications developed in countries such as Türkiye, Italy, Spain, and Australia are being conducted, and the impact of these applications on water conservation, increased yield, product quality, and sustainability is being evaluated. Additionally, solutions are proposed to address challenges encountered in digital agriculture applications, such as digital skill gaps, inadequate rural internet infrastructure, and data ownership issues. The study's findings highlight that digital agriculture offers significant opportunities for sustainable development and economic growth, emphasizing the importance of user participation, field testing, and open data platforms in innovative product development processes.

Keywords: UAV, sensor, yield, quality, precision.

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1. Introduction

The agricultural sector has undergone a continuous process of transformation in parallel with technological developments throughout history. This transformation, which began with mechanization, has progressed through several key stages, enhancing production efficiency through the use of chemical fertilizers, pesticides, and modern irrigation techniques. In recent years, rapid developments in information and communication technologies have brought the concept of digital agriculture to the forefront. Digital agriculture aims to make production processes more efficient, traceable, and sustainable through the use of advanced technologies such as sensors, unmanned aerial vehicles, artificial intelligence, big data, and blockchain [1]. These technologies enable real-time monitoring of soil, water, weather, and plant data; data-driven decision support systems increase crop yields and optimize resource use. Additionally, digitally recording every stage of the production chain from farm to table enhances food safety and transparency, thereby strengthening consumer confidence. In the face of global challenges such as climate change, depletion of natural resources, and population growth, digital agriculture applications emerge as a critical solution for developing sustainable production models.

The Food and Agriculture Organization of the United Nations (FAO) has reported that the world population will reach 9.7 billion by 2050 and that agricultural production will need to increase by approximately 56% from current levels to meet the nutritional needs of this growing population [2]. However, this increase in production must be achieved not only quantitatively but also through a sustainable approach that minimizes environmental impacts. Today, the agricultural sector accounts for approximately 26% of global greenhouse gas emissions and consumes 70% of the world's freshwater resources, creating a significant impact on ecosystems [3]. Environmental issues such as deforestation, soil degradation, and loss of biodiversity are directly linked to the uncontrolled expansion of agricultural activities. Therefore, the implementation of holistic and innovative agricultural practices that enhance production efficiency while ensuring the sustainable use of natural resources has become a critical point in ensuring food security. Solutions such as digital agriculture technologies, precision agriculture practices, and circular agriculture systems are emerging as important tools for achieving these sustainability goals.

1.1. Literature review

At this point, digital agriculture technologies come into play, enabling real-time monitoring of soil, weather, and crop data to optimize resource use, thereby reducing both costs and environmental impact [4, 5]. Thanks to sensor systems, satellite imaging, UAV-based observation tools, and AI-powered analysis software, agricultural production processes can be managed in a more controlled and efficient manner. In particular, planning the use of water, fertilizers, and pesticides according to need not only improves product quality but also contributes to the sustainable use of natural resources. In

addition, innovative product development strategies tailored to farmers' needs support sustainability in the sector in line with changing climate conditions and increasing food demand, while also positively affecting rural development and producer welfare [6]. These approaches prioritize not only increased productivity in the digitalization of agriculture but also the preservation of ecosystem services and long-term environmental balance.

This study examines digital agriculture applications, their impact on production processes, and their contribution to sustainable agriculture using examples from Turkey, Italy, and Spain. These countries, which have diverse geographical and climatic conditions, offer an opportunity for a comparative assessment of the applicability and impact of digital agriculture technologies. The study aims to contribute to sustainable agriculture policies by analyzing the impact of digital solutions such as sensors, artificial intelligence, UAVs, and blockchain on agricultural productivity, resource use, and environmental impacts.

2. Development

2.1 Digital Agricultural Technologies

Digital agriculture makes agricultural production more efficient, sustainable, and traceable thanks to technologies such as the Internet of Things (IoT), sensor systems, UAVs and satellite imaging, artificial intelligence, big data analytics, blockchain, and digital twins [4, 7] (Figure 1).

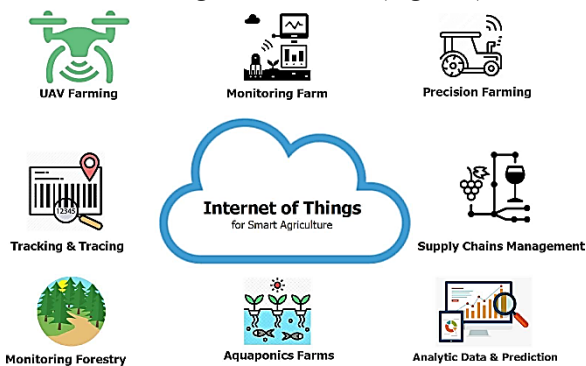


Figure 1: An illustration of IoT applications for smart agriculture [7]

These technologies continuously provide data from fields and farms, integrate this data into decision support systems, and optimize production processes in real time (Figure 2).



Figure 2: Providing continuous data from fields

IoT and Smart Sensor Systems aim to increase efficiency by continuously measuring environmental variables such as soil moisture, temperature, pH, and weather conditions. For example, it has been reported that The Yield, an Australia-based application, provides farmers with information on the most appropriate irrigation times by analyzing soil moisture and evaporation data, thereby achieving a 20% water savings. [8] (Figure 3).



Figure 3: Measuring environmental variables with Smart Sensor Systems

UAV and Satellite Imaging Systems monitor plant health through remote sensing and detect disease and pest outbreaks early (Figure 4). Additionally, VRT (Variable Rate Technology) reduces costs and environmental impact by applying fertilizers and pesticides in appropriate doses to areas where they are needed [1].



Figure 4: Monitoring plants with UAV and Satellite Imaging Systems

Artificial Intelligence and Big Data Analytics process collected data to generate yield forecasts, predict disease risks, and optimize production planning. The FarmData platform developed in Spain has been found to increase the productivity of small farmers by 15% [9].

Digital Twin Technology simulates production scenarios in real time using virtual copies of physical systems. This technology reduces waste in applications such as irrigation and fertilization, optimizing crop yield and resource use [10]. Ariesen-Verschuur et al. [11] reported a 15% reduction in water consumption in greenhouse management, while Kim and Heo [12] reported early disease detection in mandarin cultivation. In livestock farming, Symeonaki et al. [13] reported that digital twins improve nutrition and health management, and Arshad et al. [14] announced that AI-supported digital twins have led to significant improvements in welfare and productivity in sheep farming (Figure 5).



Figure 5: Digital Twin Technology: Real-Time Simulation of Production Scenarios with Virtual Copies

It has been stated that blockchain technology increases food safety by providing transparency and traceability in the supply chain [15]. These digital solutions, integrated with artificial intelligence, play a critical role in the success of sustainable and smart agriculture practices.

2.2. The Agricultural Sector in the Digitalization Process: Country Experiences

Digital agriculture applications are being implemented worldwide with various successful examples adapted to different climatic and geographical conditions. This section discusses some important studies conducted in Italy, Spain, Australia, and Türkiye (Figure 6).

The Citrus Chain Agriculture 4.0 project, carried out in the city of Sicily, Italy, combines digital sensor systems and UAV-based imaging technologies in citrus cultivation. Scuderi et al. [1] reported that the project increased fruit quality by 18% and reduced water consumption by 22%.

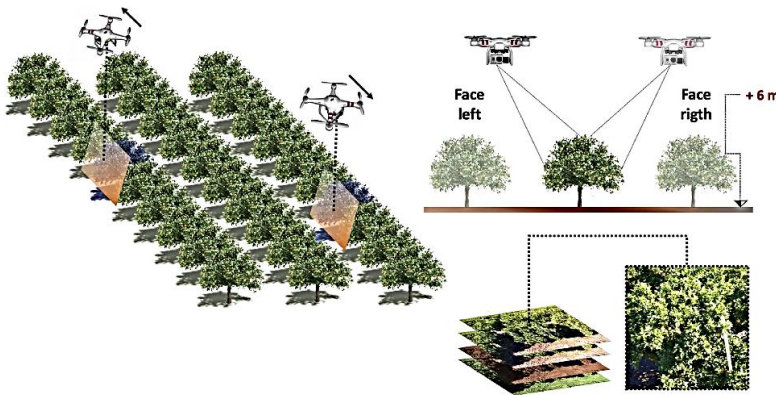


Figure 6: Digital sensor systems and UAV-based imaging technologies in citrus cultivation [16]

The Farm Data platform developed in Spain enables small and medium-sized farmers to utilize data analysis and AI-supported decision support systems. Borrero and Mariscal [9] revealed that farmers achieved a 15% increase in production efficiency thanks to disease early warning systems and yield prediction algorithms.

The Australia-based Yield app uses field-based IoT sensors to collect soil moisture and weather data, and supports irrigation and harvest planning through data analysis. According to FAO [8] data, the app has been announced to reduce water consumption by 20% and increase harvest productivity by 13%.

In Turkey, Türksat's satellite imagery and AI-based agricultural monitoring system analyzes 45 million acres of agricultural land, classifying production declarations with 98% accuracy and improving support processes [17]. In the Bursa-based GÖRSENTAM project, early warning services are provided to farmers using solar-powered stations and AI-based image processing technology [18] (Figure 7).



Figure 7: Solar-powered stations and AI-based image processing technology

2.3 Innovative Product Development Strategies

The success of digital agriculture applications depends not only on technology integration but also on the effective implementation of innovative product development strategies. In this context, three key strategies stand out.

User-centered design focuses on farmers' field experiences throughout the product development process. Scuderi et al. [1] have shown that user-centered systems increase adoption rates by 30%. User-friendly interfaces and application features facilitate the adoption of digital technology in rural areas.

Open Data and Collaboration Platforms slow down R&D processes through multi-stakeholder data sharing. Fuentes-Peñailillo et al. [4] reported that open data usage increases the accuracy of disease early warning systems by 20%. Kernecker et al. [19] emphasized that collaboration networks between farmers, technology developers, academics, and policymakers play a critical role in the widespread adoption of digital agriculture.

Environmental and Economic Impact Assessments evaluate the sustainability and cost-effectiveness of developed products. Borrero and Mariscal [9] reported that AI-supported systems reduced carbon emissions by 12% and costs by 10%. Papadopoulos et al. [20] revealed that agricultural sensors based on life cycle analysis reduced energy consumption by 15%.

Also, pilot applications are also very important. Rose et al. [21] demonstrated that mobile application pilot tests improved usability by 25%. These strategies strengthen the social, environmental, and economic contributions of digital agriculture technologies.

2.4 Sustainability of Digital Agriculture

Agricultural production causes serious environmental problems such as overuse of water resources, soil pollution, loss of biodiversity, and greenhouse gas emissions. FAO [2] reports that 70% of the world's freshwater resources are used in agriculture and 24% of global greenhouse gas emissions come from agricultural activities. In this context, digital agriculture applications offer powerful tools for achieving sustainable agriculture goals.

Smart irrigation systems use sensors to monitor soil moisture, ensuring that irrigation is applied only when needed (Figure 8). According to FAO [8] data, the Yield app has achieved 20-30% water savings on Australian farms. Similarly, UAV and satellite imaging systems reduce pesticide use by detecting diseases and pests early [4].

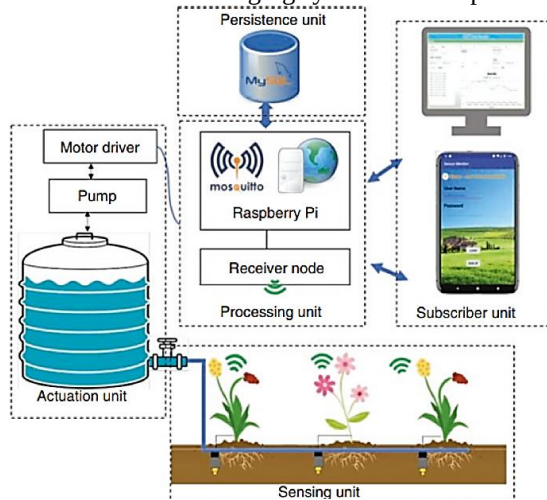


Figure 8: Intelligent and automatic irrigation system based on internet of things using fuzzy control technolog [22]

Artificial intelligence-supported big data analytics reduces greenhouse gas emissions by ensuring the correct timing and dosage of fertilization and pesticide application. Scuderi et al. [1] reported that these systems reduced greenhouse gas emissions by 12%. FAO field studies in Turkey also show that early warning systems reduce carbon emissions by 12-15%. EBRD-supported projects report that automation systems reduce diesel consumption by 20%, thereby reducing energy-related emissions [23].

Additionally, sensor networks and data analytics continuously monitor soil nutrient cycles and pH balances to prevent erosion and salinization. Envico's digital agriculture platform has been reported to slow down agricultural land loss by 7% and support microbial diversity, thereby protecting soil health [23, 24].

In addition to these efforts, mobile applications and low-cost Internet of Things (IoT) devices have been reported to facilitate small farmers' access to digital agriculture opportunities (Figure 9). For example, the "Digital Villages" project implemented in Turkey through a joint initiative between FAO-EBRD has reduced water and energy consumption by 18%, increased organic product certification and market access through blockchain-based systems [25].



Figure 9: Mobile applications and low-cost Internet of Things (IoT) devices for smart agriculture

2.5 Rural Development and Digitalization

Digital agriculture applications not only improve production processes, but also serve as an important tool for supporting rural development. Agricultural digitization creates new jobs in rural areas, encourages young people to stay in villages, and increases women's participation in production processes [2].

Digital platforms developed specifically for small and medium-sized farmers contribute to reducing economic inequalities. The FarmData application in Spain has reduced inequalities in access to information and technology by enabling small producers in rural areas to benefit from AI-supported systems [9].

Digitalization also contributes to the development of rural infrastructure and the widespread use of internet and mobile technologies. Research shows that strengthening digital infrastructure in rural areas revitalizes the local economy and social life [4].

Furthermore, the widespread use of digital agriculture technologies by women farmers and young entrepreneurs significantly contributes to gender equality and youth employment.

3. Result

The findings of this study reveal the impact of digital agriculture applications on agricultural production processes with concrete data based on national and international examples. As a result of the analyses and case studies conducted, it has been determined that digital agriculture technologies increase production efficiency by 13-20%, save 20-22% in water consumption, and improve product quality by 18%. In particular, smart irrigation systems and artificial intelligence-based data analytics have increased farmers' decision-making speed while significantly reducing environmental impacts. Disease early warning systems have been found to reduce greenhouse gas emissions by 10-15% and significantly reduce the use of chemical pesticides. The Yield project in Australia achieved a 20% water savings and a 13% increase in productivity, while the Citrus Chain Agriculture 4.0 application in Italy achieved an 18% improvement in fruit quality and a 22% reduction in water consumption. In Turkey, Türksat's AI-supported satellite imaging project has enabled declaration audits to be carried out with 98% accuracy on 45 million decares of land. GÖRSENTAM stations based in Bursa have saved water and labor in more than 80 farms in the Marmara and Aegean regions.

All these applications support environmental sustainability and facilitate access to digital agriculture solutions for small and medium-sized farmers. However, the lack of digital infrastructure, data security concerns, investment costs, and farmers' digital literacy levels are the primary factors limiting the widespread adoption of these applications. Active participation of farmers in innovative product development strategies, the establishment of open data sharing platforms, and the development of environmentally impact-focused product designs should be prioritized. Additionally, the need to assess the long-term impact of digital agriculture applications on climate change mitigation, resource efficiency, and rural development through detailed field studies is one of the key recommendations of this study. Support for initiatives and technological solutions in this area by policymakers and investors will play a critical role in building a sustainable and productive agricultural economy.

4. Discussion

The digital farming applications analyzed in this study demonstrate substantial improvements in agricultural efficiency and sustainability, consistent with existing literature. In Italy, the Citrus Chain Agriculture 4.0 project achieved an 18% increase in fruit quality and a 22% reduction in water use, supporting Scuderi et al. [1] on IoT-based sensor systems for resource optimization. FarmData in Spain boosted smallholder productivity by 15%, aligning with Borrero and Mariscal [9] on AI-driven decision support systems. In Australia, yield-based irrigation reduced energy consumption by 20% and increased harvest efficiency by 13%, confirming FAO [8] findings on smart irrigation. In Turkey, the Türksat AI project audited 45 million decares of farmland with 98% accuracy, demonstrating the scalability of satellite-based monitoring [17].

Nonetheless, barriers to widespread adoption reflect systemic challenges in the literature. Kernecker et al. [19] identify poor rural internet access and low digital literacy as key constraints. Rose et al. [21] show a 25% usability improvement in pilot programs, underscoring the value of user-centered design. Fuentes-Peñailillo et al. [4] report a 20% increase in disease prediction accuracy through open data, highlighting the need for data-sharing platforms. Finger et al. [6] stress that multi-stakeholder collaboration is essential for resilient digital agriculture. Prioritizing farmer engagement, low-cost IoT solutions, and supportive policies is crucial for global scalability.

5. Conclusion

The integration of digital farming technologies in agricultural production systems offers major opportunities for sustainability, efficiency and optimisation of resources. The combined use of Internet of Things sensors, artificial intelligence-supported Decision Support Systems, UAVs and satellite technology has produced tangible results. However, widespread adoption of these technologies requires comprehensive solutions addressing infrastructure bottlenecks, high start-up costs, digital illiteracy and data security. In the future, the adoption of user-centred approaches to product development, the promotion of low-cost technology solutions through public-private partnerships and the creation of open data sharing platforms will accelerate the global diffusion of digital farming and the transformation of agricultural production.

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