

Analysis of the Role of Information Technology in Supporting Environmentally Friendly Agriculture in the Digital Age

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Abstract. Global pressures such as population growth, resource degradation, and climate change demand the implementation of more effective sustainable agriculture. The use of information technology (IT) such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and geospatial information systems has opened up significant opportunities to optimize resource use while minimizing environmental impact. This study employs a literature review method, analyzing journals, books, and articles related to IoT, precision agriculture, smart irrigation, and digital hydroponics, to identify the role, benefits, and challenges of IT implementation in the agricultural sector. The findings indicate that IT supports precision agriculture through real-time monitoring of soil and crops, smart irrigation that saves water and energy, and smart hydroponics that enhance productivity and resource efficiency. In Indonesia, pilot projects such as automated irrigation and IoT-based monitoring have demonstrated increased yields on a small-to-medium scale. However, widespread adoption is still hampered by high initial costs, infrastructure limitations, and low digital literacy among farmers. This study concludes that the implementation of IT in environmentally friendly agriculture requires policy support, inclusive financing, and sustainable mentoring programs to ensure sustainability and equitable benefits.

Keywords: Information Technology, Precision Agriculture, Internet of Things, Sustainable Agriculture, Digital Age

1. Introduction

Global pressures of population growth, resource degradation, and climate change make sustainable agriculture an urgent necessity. Digital transformation in the agricultural sector offers significant opportunities. Information Technology (IT)-including the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and geospatial information systems-enables data-driven farming practices that optimize water, fertilizer, and labor use, reducing environmental externalities while improving production efficiency. Recent systematic reviews confirm that the integration of AI-sensing and IoT on cultivated land opens up real pathways to improve the precision of agronomic interventions and minimize ecological impacts (Chien et al., 2020 MDPI 2025)

One of the most influential applications of IT is precision agriculture, which is the customization of agronomic inputs according to the spatial-temporal needs of crops. Soil sensor technology, drones/multispectral imagery,

and analytics platforms enable regular monitoring of soil conditions, moisture, and crop stress so that water, fertilizer, and pesticide applications can be targeted. This approach has been shown to reduce water consumption and agro-chemical use and improve local environmental quality when combined with adaptive management practices (Arias et al., 2022) The implementation of IoT-based smart irrigation, which regulates watering based on soil moisture data and weather forecasts, has shown water savings and reduced energy emissions across multiple studies (Shamshiri et al., 2018; Wahyudi et al., 2025)

The integration of AI and predictive models strengthens decision-making, from early detection of pests to prediction of nutrient requirements and optimal harvest times. Machine learning-based Decision Support Systems (DSS) can process sensor data, satellite/drone imagery, and weather forecasts to produce proactive and scalable recommendations, reducing intuitive experimentation that risks overuse of inputs (Kamilaris et al, 2018, Springer, 2025) Economically, agricultural digitization can increase productivity per unit area and open digital market access, although its utilization is strongly influenced by local context, infrastructure availability, and user capacity (Rose, D. C., & Chilvers, 2018).

In the Indonesian context, various applied studies and pilot projects (eg. IoT hydroponic systems, automated irrigation, and simple monitoring platforms) demonstrate the real potential of IT to improve resource efficiency and yields at the small-medium scale (Sisfokomtek, 2024, Wahyudi et al., 2025) (Ejournal Sisfokomtek, 2024, Wahyudi et al, 2025) However, barriers such as limited rural connectivity, initial cost of devices and data services, maintenance needs, and low digital literacy of farmers are still the main obstacles (Klerkx et al., 2019) This prompts the need for inclusive policy and business models, such as co-financing, technology-as-a-service, and mentoring programs, so that the use of IT in eco-agriculture can be widespread, equitable, and sustainable.

2. Methods

This research approach utilizes a literature review method by examining a variety of relevant scientific sources, including reputable international journals, national journals, conference proceedings, books, and recent research articles within the last five years. The literature analyzed was purposively selected with a focus on key issues: Internet of Things (IoT) in agriculture, the concept of precision agriculture, smart irrigation innovations, and the application of digital hydroponics.

The analysis process was conducted by screening publications that addressed the role of information technology in supporting resource efficiency, environmental sustainability, and increased agricultural productivity. Articles that met the criteria were then compared to identify patterns of benefits, barriers to implementation, and policy recommendations. Thus, this method produces a comprehensive synthesis of opportunities and challenges related to the application of information technology in the context of environmentally friendly agriculture, both on a global scale and in Indonesia.

3. Results and Discussion

A. The Concept of Environmentally Friendly Agriculture in the Digital Age

The concept of environmentally friendly agriculture basically emphasizes the principle of sustainability by maintaining, ecosystem balance, reducing carbon emissions, and minimizing the use of synthetic chemical inputs that have the potential to damage the environment. In the digital era, this paradigm is increasingly relevant as global challenges such as climate change, soil degradation, and the world's increasing food needs demand technology-based solutions. The integration of the Internet of Things (IoT), big data analytics and artificial intelligence (AI) creates a data-driven farming system that allows farmers to make precise decisions.

For example, the use of soil moisture sensors and drone-based monitoring systems can provide real-time data on crop water requirements. This helps farmers adjust irrigation so that they only use water according to actual needs. In addition, the use of AI-based predictive modeling can detect potential pest attacks or plant diseases early, so

that the use of pesticides can be reduced. Thus, digital technology strengthens environmentally friendly practices while increasing agricultural productivity (Arias et al, 2022 Chien et al., 2020 Shamshuri et al., 2015)

B. The Role of Information Technology in Agricultural Resource Management

Information Technology plays a central role in the efficient use of natural resources, particularly water, fertilizer, and energy. In the practice of precision agriculture, IoT enables the monitoring of land conditions through sensors connected to digital platforms. The data collected can be processed by AI algorithms to provide optimal recommendations on fertilization, watering, or crop rotation.

Studies in Indonesia show that the application of IoT-based smart irrigation can save water up to 30%, as well as increase horticultural agricultural yields up to 20% compared to conventional methods (Wahyudi et al., 2025) Globally, the application of AI-based decision support systems (DSS) is also proven to reduce the use of excess pesticides and fertilizers, which is one of the causes of soil degradation (Kamilaris et al, 2018) In addition, the integration of renewable energy in agricultural technology, such as solar panels to operate intelligent water pumping systems, can reduce carbon emissions from agricultural activities.

C Digitization of Agricultural Supply Chains

Apart from production, digital transformation also has a major impact on the agricultural supply chain. Supply chain digitization through e-commerce platforms, agribusiness applications, and blockchain technology allows farmers to access a wider market with transparent prices This reduces the role of middlemen and increases smallholder farmers profit margins.

In Indonesia, the use of applications such as Taniklub and other agritech platforms is proven to shorten the distribution chain, expand market access to urban areas, and reduce food loss in fresh products (Purwandari et al, 2020) On a global scale, the application of blockchain in the agricultural sector increases consumer confidence as the distribution history of products can be transparently tracked from farm to table (Rose, D. C., & Chilvers, 2018) Thus, digitizing the supply chain not only strengthens the bargaining position of farmers, but also improves national and global food security.

D. Digital Literacy and Farmer Readiness

The readiness of human resources is one of the main determinants of the success of digital agricultural transformation. Low digital literacy among farmers, especially in rural areas, remains a significant obstacle. Many farmers are not accustomed to using IoT devices, digital farming applications, or utilizing sensor-generated data in decision-making.

To address this challenge, various community-based training programs have been developed, such as digital field schools and peer-to-peer learning. Studies (Prasetyo et al., 2022) show that community-based training improves farmers' skills in operating IoT applications, as well as fosters confidence in the adoption of new technologies. In fact, a continuous mentoring program proved to be more effective than a one-time training, as it provided an opportunity for farmers to master the technology gradually. This strengthens the argument that digital literacy is the key to agricultural sustainability in the digital era.

E Barriers to Information Technology Implementation

Although information technology brings many benefits, its implementation in the agricultural sector is not free from various barriers. First, the initial investment costs for devices such as sensors, drones, and analytical infrastructure are still relatively high, making it difficult to reach small-scale farmers (Unimal, 2022) Second, limited internet infrastructure in rural areas hinders the application of IoT-based technologies that require stable connectivity (Klerkx et al., 2019) In addition to technical factors, socio-cultural barriers also play a role. Many farmers are still reluctant to abandon traditional methods because they are considered more familiar, safer, and

less risky. The study (Zanah et al., 2024) confirms that this social resistance can slow down the adoption of digital technologies despite their clear economic benefits. Therefore, technology adoption strategies must be inclusive, take into account local socio-cultural conditions, and involve the active role of government and non-governmental organizations.

F. Concept Recommendation: Eco-Digital Agriculture Framework

Based on the literature review, this research recommends the Eco-Digital Agriculture Framework as a strategic framework for the development of technology-based eco-agriculture. The framework includes four main elements.

1. Smart Monitoring - Monitoring soil, crop, and microclimate conditions through IoT, multispectral drones, and satellite imagery to provide accurate real-time data.
2. Resource Efficiency - Optimizing the use of agricultural inputs such as water, fertilizers, and pesticides through precision agriculture approaches to reduce soil and water pollution.
3. Resilient Farming Application of AI and predictive models to mitigate the impact of climate change, anticipate pest attacks, and maintain food supply stability.
4. Inclusive Adoption Public policy support, digital literacy, and inclusive financing schemes to ensure technology is accessible to small and medium-scale farmers.

This framework is not only relevant in Indonesia, but can also be applied to other developing countries. Multi-stakeholder collaboration between government, academia, private sector, and farming communities is required for inclusive and sustainable technology adoption (Rose et al., 2018 Arias et al, 2022).

4. Conclusion

The study results show that the application of Information Technology (IT) plays an important role in realizing environmentally friendly agriculture in the digital era. The integration of IoT, big data, artificial intelligence, and geospatial information systems has supported precision agriculture, increased resource use efficiency, and reduced negative impacts on the environment. The implementation of smart irrigation, sensor-based monitoring, and digital hydroponics can save water, reduce pesticides, and increase crop productivity.

In addition, supply chain digitization opens up wider market access opportunities for farmers, while digital literacy and community mentoring are proven to improve farmers' readiness to adopt technology. However, IT adoption still faces barriers such as initial investment costs, limited digital infrastructure, and socio-cultural resistance.

To address these challenges, the Eco-Digital Agriculture Framework is recommended as a strategic model. This framework emphasizes smart monitoring, resource efficiency, AI-based agricultural resilience, and inclusive adoption through policy support, innovative financing, and improved digital literacy. With targeted implementation, digital agriculture can not only increase farmers' productivity and income, but also contribute to environmental sustainability and global food security.

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