



# Strategic implementation of AI IoT and Big Data technology in improving upstream to downstream agricultural efficiency

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## ABSTRACT

This paper examines the role of Artificial Intelligence (AI), the Internet of Things (IoT), and Big Data in improving agricultural efficiency from upstream to downstream processes. These technologies enable large-scale data processing, advanced analysis, and automation to optimize agricultural activities, including land preparation, pest control, irrigation, and crop distribution. IoT facilitates real-time data collection through interconnected devices, enhancing monitoring and decision-making without direct human intervention. This study employs a qualitative literature review method by analyzing various relevant sources. The findings indicate that the integration of AI, IoT, and big data significantly enhances agricultural efficiency and productivity through the development of smart farming systems. These systems allow farmers to monitor soil conditions, weather patterns, irrigation levels, and crop health in real time. AI algorithms can predict crop yields, detect early signs of plant diseases, and recommend optimal planting schedules based on historical and real-time data. IoT sensors continuously transmit field data, enabling rapid responses to environmental changes, while big data analytics supports data-driven decision-making by aggregating and interpreting large volumes of information. Beyond increasing productivity, the integration of these technologies also promotes sustainable agricultural practices by optimizing resource use, reducing waste, and minimizing environmental impact. As global food demand continues to rise, the adoption of AI, IoT, and big data is essential to ensure sustainable and efficient agricultural development in the future.

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## Introduction

Today's technological advances show that humans are entering a new era in the industrial world, namely the technology industry (Ratna, 2023). Technology has become part of human life today, where almost all human activities use technology as a medium of work, for example, using transportation such as cars for work, mobile phones as a means of communication with various platforms, the internet, artificial intelligence, and other technologies. This indicates that technology is no longer merely a tool but a necessity that shapes human behavior, culture, and even ways of thinking. Amidst this rapid technological advancement, humans are required to use technology wisely and responsibly for the common good. The wise and responsible use of technology will have a positive impact, one of which is in the agricultural industry. If used irresponsibly, technology can lead to environmental degradation or even social inequality, but when applied ethically, it can be a solution to various global problems such as food security and sustainability. The attractiveness of the world community towards coffee, for example, is not only because of its unique taste but also because of its historical, traditional, social, and economic value. The global demand for coffee and other agricultural commodities has encouraged the agricultural sector to innovate in order to meet market needs without sacrificing environmental balance.

Agriculture is one of the industries that will benefit from technological advances, especially in improving agricultural production efficiency, from land cultivation to harvesting and distribution of produce. The integration of technology in agriculture is no longer optional but necessary to maintain productivity and competitiveness in the global market (Nur et al., 2024). Technologies such as AI IoT will help farmers

to be more efficient in land cultivation, weather forecasting, pest control, and even distribution during harvest. The use of AI IoT reduces the risk of crop failure because farmers can make decisions based on real-time data and accurate predictions. AI IoT is artificial intelligence technology that can connect physical devices to the internet to communicate and collect data without human intervention and is more effective in delivering results. Examples of AI IoT intelligence are agricultural robots and agricultural drones that can care for and fertilize crops more effectively. These tools reduce manual labor and increase accuracy in planting, fertilizing, and harvesting. In addition, this technology can help predict weather, humidity, and even analyze how much harvest will be obtained in this period (Luthfi, 2023). The combination of AI IoT and big data allows farmers to identify patterns in soil health, water usage, and crop growth that were previously invisible, enabling precision farming that is both cost-efficient and environmentally friendly. AI IoT and big data are technological innovations that are very effective for increasing agricultural production today if they are further developed with a good and appropriate system (Teguh et al., 2022).

This paper will answer three main questions: What are AI IoT and big data? What is upstream to downstream agriculture? How can AI IoT and big data be implemented to improve the efficiency of upstream to downstream agriculture? These questions are crucial to understand the role of technology in transforming agriculture from a traditional, labor-intensive practice to a data-driven, efficient, and sustainable industry. In analyzing this issue, the author uses a qualitative literature review method, in the form of books, articles, and journals from previous studies as sources of analysis. This method allows for a comprehensive understanding of how technology has

been applied in various contexts and what challenges still exist in its implementation. The purpose of this paper is to provide an overview of the implementation of AI IoT and Big Data in agriculture, which is more efficient than primitive (manual) agriculture that is less than optimal in terms of results. This comparison between manual and technology-assisted farming highlights the importance of innovation in meeting the growing demand for food worldwide. As stated above, this paper was written to show that agricultural yields are not optimal when farming is done manually without the use of AI IoT and Big Data technology, and to provide the answer that technology has a positive impact when used wisely. Ultimately, the findings are expected to inspire policymakers, farmers, and technology developers to collaborate in creating an inclusive agricultural ecosystem that benefits both producers and consumers while maintaining sustainability.

## Method

This paper will be examined using qualitative literature study methods by referring to various sources such as books, scientific articles, journals, and other literature sources related to the theme of this paper. Based on the various sources found, this paper will provide broad insights into the current reality of the world, which is in a rapidly growing technology industry with various platforms offered, such as AI, IoT, and Big Data, which enable the agricultural industry to be more optimal and efficient in production. Advances in AI, IoT, and Big Data technology provide new enthusiasm and hope for the agricultural industry to be even more productive (Malahati et al., 2023)

However, the application of technology in the agricultural sector also faces various challenges, such as limited access to digital infrastructure, high investment costs, and

farmers' lack of skills in operating new technologies. In order to avoid a gap between modern and traditional farmers, support from the government, academics, and the private sector in the form of education, training, and technology subsidies is needed (Muhammad, 2021). In addition, the use of technology must take into account sustainability aspects, so that it not only increases productivity but also preserves the environment through more efficient management of water, soil, and pesticides. Thus, AI, IoT, and Big Data are not only a means of increasing crop yields, but also an important instrument for creating an environmentally friendly precision farming system that supports long-term food security.

## Results and Discussion

### *AI IoT and Big Data*

AI, or Artificial Intelligence, is a branch of computer science designed to create systems or machines capable of performing human tasks, requiring human intelligence programming (Agus, 2025). It is important to note that AI is not a new field of study in computer science. AI began to develop in 1940, but it was not until the 1950s, specifically in 1956 at Dartmouth College, that AI was officially introduced. Since then, AI has undergone a major transformation from a mere theoretical concept to one of the most revolutionary technologies in human history. AI has not only driven scientific progress, but also accelerated the evolution of global industry towards a digital era that is fully automated and data-driven (Ratna, 2023). The main goal of AI is to develop algorithms that enable computers or machines to have abilities similar to human intelligence, such as thinking, planning, learning, understanding language, recognizing patterns, and making decisions autonomously. This role makes AI the foundation for new innovations in

various fields of life. For example, in the field of health, AI can assist in the diagnosis of diseases with high accuracy, support radiology analysis, and even develop new drugs through molecular simulation (Ratna, 2023).

In line with AI, another equally important technological development is the Internet of Things (IoT). IoT was first introduced by Kevin Ashton in 1999 (Yudha, 2007). IoT is essentially a concept that extends internet connectivity not only to computers or smartphones, but also to various everyday physical objects equipped with sensors, software, and communication networks. Thus, these objects can connect with each other, exchange data, and perform remote control automatically without the need for direct human intervention. The way IoT works is usually supported by a combination of sensors, embedded systems, internet networks, and data analytics devices. Sensors embedded in an object function to capture information from the environment, such as temperature, pressure, location, or movement. This data is then sent to a processing center via the internet to be analyzed, monitored, and even acted upon.

Access to AI IoT is inseparable from the collection of data gathered in a program known as big data. Big data is a collection of data that is extremely large, diverse, and continues to grow at a rapid rate, making it impossible to manage effectively using traditional data processing methods (Kurniawan et al., 2024). The concept of big data is usually characterized by three main features known as 3V (a very large amount of data, which can reach terabytes to petabytes), velocity (the speed at which data flows in and is processed in real-time), and variety (the diversity of data forms, whether structured, semi-structured, or unstructured, such as text, images, videos, and IoT sensors) (Manuaba et al., 2022). In this context, big data has great potential to

generate valuable insights through in-depth analysis, for example in trend prediction, data-driven decision making, and new service innovation.

Furthermore, the synergy between AI, IoT, and big data creates an intelligent ecosystem that allows industries and governments to operate with unprecedented efficiency. In agriculture, for instance, IoT sensors installed in fields can provide real-time data on soil moisture, while AI algorithms analyze this data to recommend precise irrigation schedules. In the manufacturing sector, predictive maintenance powered by AI can prevent machine breakdowns, saving costs and reducing downtime. Big data analytics also enables governments to design more effective public policies by analyzing population movement, economic patterns, and social behavior in real time (Chakim et al., 2023). In education, AI-driven platforms can personalize learning according to individual student needs, while IoT-enabled classrooms enhance interactivity and engagement. At the same time, the integration of these technologies also raises challenges related to data privacy, cybersecurity, and ethical use of AI. Therefore, developing a robust regulatory framework and educating society about digital literacy becomes crucial to ensure that the benefits of AI, IoT, and big data can be enjoyed inclusively and responsibly (Bagaskoro, 2024).

### *Upstream to downstream agriculture*

Upstream to downstream agriculture is an agromaritime program in the field of agriculture to facilitate farmers in processing and marketing. The main objective of this program is to empower farmer organizations and improve the quality of human resources and cooperative partnerships (Lukman, at.al, 2020). This program is designed to integrate the entire agricultural value chain, from the provision of production facilities,

processing of products, to distribution to the market. Through the support of modern technology, farmers can more easily access information about climate, market prices, and effective cultivation techniques. As a result, the production process not only runs more efficiently, but also produces products of a quality that can compete in both national and international markets (Nandika, 2017).

On the other hand, the upstream-to-downstream approach also aims to strengthen farmers' bargaining position through solid institutions, such as farmer cooperatives and joint business groups. Through these institutions, farmers no longer work individually, but in organized and highly competitive networks (Sri et al., 2023). The marketing of agricultural products is supported by the digitization of the trading system and partnerships with various sectors, including the processing industry, banking, and exporters. With this model, agriculture is not merely a production activity, but a strategic sector that can improve farmers' welfare, maintain environmental sustainability, and drive regional economic growth (Khanifatul et al., 2019).

In addition, the upstream-to-downstream agriculture program encourages the adoption of innovative financing schemes that make it easier for farmers to access capital without being trapped by middlemen or high-interest loans. Training programs and workshops are also regularly held to improve farmers' capacity in managing agribusiness, mastering post-harvest technology, and utilizing digital platforms for marketing. Moreover, the integration of this program helps reduce post-harvest losses, which are often a major challenge in traditional farming systems. Local governments play an important role by providing infrastructure support such as irrigation, transportation, and storage facilities to ensure smooth distribution of

agricultural products. Collaboration with universities and research institutions also contributes to the development of new, more adaptive and environmentally friendly cultivation technologies. Ultimately, this approach is expected to create a sustainable agricultural ecosystem where farmers are not only producers but also active players in the value chain who can make strategic decisions to improve their livelihoods (Billah et al., 2019).

### *Implementation of AI IoT and Big Data in improving agricultural efficiency*

AI IoT and big data are new innovations developed to assist humans in various sectors of life today, one of which is agriculture. The use of AI, IoT, and Big Data technologies in upstream to downstream agriculture will make a significant contribution to farmers, starting from the stages of production preparation, cultivation, and distribution (Pangestika et al., 2020). In the production preparation stage, land determination and cultivation are key to farmers' success. Therefore, the use of AI, IoT, and Big Data will greatly assist farmers in monitoring soil conditions, temperature, humidity, pH levels, and nutrient content in real-time with installed sensors.

AI IoT and Big Data in this case are very effective and efficient programs where data obtained from the land to be cultivated is reanalyzed by the Big Data system to find patterns of correlation between environmental factors and crop yields. Furthermore, AI processes this data to provide more accurate recommendations, such as determining the appropriate crop varieties for the land conditions, estimating irrigation needs, and developing an appropriate fertilization schedule. With this application, farmers are not only assisted in reducing climate uncertainty, but are also

able to increase productivity through more efficient and environmentally friendly use of resources (Agus, 2020).

The accuracy and scale of AI IoT and big data usage is so extensive that it does not stop at the production preparation stage but continues to the next stage, namely cultivation or the production process. At the cultivation stage, the integration of AI, IoT, and Big Data is increasingly visible and more effective than manual cultivation (Erwin et al., 2023). One of the tools that can be used with this system is an AI-based agricultural drone, used for monitoring plant growth, early detection of diseases, and precise spraying of pesticides and fertilizers according to the needs of plants at specific points (precision farming). The use of agricultural drones helps improve the effectiveness of cultivation, and the use of tools such as agricultural drones will also reduce operational costs and chemical waste while maintaining the balance of the agricultural ecosystem. In addition, the use of automatic harvesting machines equipped with IoT sensors and AI algorithms can predict the right time for harvesting, so that the quality of agricultural products can be optimally maintained. Big Data plays a role in analyzing market demand trends so that farmers can adjust production volumes to consumer needs. Thus, the agricultural production process is no longer traditional and speculative, but data-driven and market-oriented (Andriyani et al., 2024).

As the concept of upstream to downstream agriculture does not only stop at the cultivation and harvesting stages, but also includes how the produce can be distributed or marketed. AI IoT and Big Data programs will also help farmers find marketing outlets (Andi, 2023). This program is supported by an IoT system that will track the movement of products from the field to the consumer, thereby ensuring greater transparency and food safety. In addition, AI helps analyze consumer behavior and market preferences,

which can be used for branding strategies, product diversification, and competitive pricing. Meanwhile, Big Data enables the formation of a digital agricultural ecosystem through e-commerce platforms, blockchain, and marketing applications that connect farmers directly with consumers without intermediaries. This not only cuts the long distribution chain but also increases farmers' income (Wahyudi et al., 2025).

Therefore, to achieve more productive agriculture, the use of technology has become an important alternative for farmers to learn about and utilize in order to increase their capacity to produce good quality yields. Ultimately, AI, IoT, and Big Data technologies in upstream to downstream agriculture are not merely technical innovations, but rather a comprehensive transformation that creates more productive, sustainable, and globally competitive agriculture. Technology has a positive impact on the future progress of the agricultural industry.

## Conclusion

The development of AI Artificial Intelligence, IoT Internet of Things, and Big Data technologies has proven to bring fundamental changes to the agricultural sector. Their application has enabled agricultural production processes, which previously relied on intuition and traditional experience, to become more measurable, systematic, and data-driven. With IoT sensors, field data can be collected in real time; AI processes and analyzes this data to generate accurate recommendations; while Big Data provides a broad information base for understanding climate patterns, land conditions, and market trends. The synergy of these three technologies reduces uncertainty, lowers production costs, and increases resource utilization efficiency. In addition the implementation of this technology not only impacts the upstream

stage, but also throughout the agricultural value chain to the downstream stage. In the cultivation process, AI-based drones and automated machines can improve precision in crop care and harvesting, resulting in higher quality and more environmentally friendly agricultural products. Downstream, IoT and Big Data-based supply chain digitization systems open up wider and more transparent market access for farmers. Direct access to consumers through digital platforms and e-commerce shortens distribution channels, increases farmers' income, and strengthens their bargaining position in the global agricultural ecosystem. The integration of AI, IoT, and Big Data in upstream to downstream agriculture is not merely a technical innovation, but a strategic transformation towards sustainable agriculture. This technology makes the agricultural sector more adaptive to the challenges of climate change, market price fluctuations, and global food security demands. Moreover, their implementation also promotes farmer empowerment, strengthens agricultural institutions, and creates an inclusive and highly competitive agricultural system. Thus, agriculture is no longer merely a production activity, but a driving force for economic, social, and environmental development that can meet the needs of the modern era.

Based on the conclusion, it is strongly recommended that governments, academic institutions, and agricultural industry stakeholders actively promote the wider and more equitable adoption of AI, IoT, and Big Data technologies across all levels of the agricultural sector. Special attention should be given to smallholder and medium-scale farmers who often face barriers to accessing modern technology, as they represent the backbone of global food production. This effort should include comprehensive and continuous training programs, workshops,

and digital literacy initiatives to ensure that farmers are not only able to access these technologies but also understand how to interpret and apply the data-driven insights they provide to improve productivity and decision-making. Moreover, the development of robust digital infrastructure, particularly the expansion of reliable and affordable internet connectivity in rural and remote areas, is crucial to enable real-time data collection and seamless integration of IoT devices. Policy frameworks should provide financial incentives, subsidies, and partnerships to encourage investment in smart farming technologies while ensuring affordability and inclusivity. Collaboration between governments, private sectors, start-ups, and research institutions should be strengthened to foster innovations tailored to local agricultural challenges, climate conditions, and market demands. Such a multi-stakeholder approach would not only improve production efficiency but also enhance sustainability, empower farmers, and build a resilient agricultural ecosystem capable of meeting global food security demands in the face of climate change and economic uncertainties.

## **Declaration of Ownership**

This article is my original work.

## **Conflict of Interest**

There is no conflict of interest to declare in this article.

## **Ethical Clearance**

This study was approved by the institution.

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