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SMART AGRICULTURE IN THE DIGITAL ERA: A REVIEW ON HARNESSING AI, ML, AND IOT FOR A SUSTAINABLE FUTURE

Sanjeev Khan[1*], Nutan Pathania[2], and Pawan Kumar[2]

[1*-]Department of Data Science and Artificial Intelligence, Himachal Pradesh University, Summerhill, Shimla, India

[2-]Department of Computer Science, Himachal Pradesh University, Summerhill, Shimla, India

[1*]Correspondence author email address: sanjeevkhan.hpu@gmail.com

ABSTRACT: The combination of the Internet of Things (IoT), artificial intelligence (AI), and machine learning (ML) is powering the digitalization of agribusiness, ushering in a new era of sustainability, digitization, and efficiency in agriculture. This review paper discusses these technologies' present trends, challenges, and opportunities in the agriculture sector. These technologies also support predictive analytics, optimizing irrigation schedules, pest control, & the distribution of resources, leading to significant cost reductions and increased productivity. The IoT plays a critical role by facilitating continuous tracking of the surrounding environment, equipment, and the logistics of the trade, creating smarter farming practices. The use of these technologies, though, is not without its challenges, with high capital outlays for initial investment, a shortage of technical knowledge, and security concerns around data. Furthermore, the need for infrastructure development, especially in rural areas, remains a significant barrier to widespread implementation. The paper also discusses the potential of The Internet of Things, Artificial Intelligence, and Machine Learning in the future to drive sustainable agricultural practices, improving supply chain transparency, and enhancing food security. In summary, while there has been considerable progress, more research and innovation need to be achieved to overcome current hurdles and attain the full potential of these technologies in transforming world agribusiness.

KEYWORDS: Digital Transformation; Agribusiness; Machine Learning; Artificial Intelligence; IoT; Smart Farming; Predictive Analytics.

The agriculture sector is experiencing a paradigm change caused by rapid developments in the Internet of Things (IoT), artificial intelligence (AI), and machine learning (ML). The three technologies have been identified as the primary drivers of digital transformation, tackling critical concerns such as climate change, food security, labour scarcity, and resource optimization (Pandey & Mishra, 2024). The convergence of ML, IoT and AI is transforming agriculture with the addition of data-driven decisions, digitization, and statistical analysis, making it more efficient, sustainable, and profitable (Aijaz et al., 2025).

Background and Importance of Digital Transformation in Agribusiness

Agribusiness, previously, has been based on traditional farming practices rooted in manual labor and low technological usage. Due to the worldwide population increase, which is expected to reach more than 9.7 billion by 2050, it is time to transition to sustainable and technology-facilitated agriculture solutions (Shahab et al., 2024). The Food and Agriculture Organization (FAO) also approximates that food production should increase by at least 70% to cope with the needs of the future, stressing the importance of smart, data-driven initiatives in agriculture (Jararweh et al., 2023).

IoT in Smart Agriculture

Digital transformation in agribusiness includes the convergence of ML, IoT and AI to drive several dimensions of agriculture, such as precision agriculture, crop health monitoring, supply chain management, and automated irrigation (Mohyuddin et al., 2024). All of these technologies support real-time monitoring, predictive analysis, and smart decision-making, resulting in optimal utilization of resources and minimum environmental impact (Araújo et al., 2023). In addition, AI-driven models promote climate resilience through historical and current weather pattern analyses, enabling the prediction of extreme weather events (Karunathilake et al., 2023).

Integration of ML, IoT, and AI in Smart Agriculture

ML, IoT, and AI play critical roles in modernizing agribusiness by shifting traditional farming processes into smart and automated systems.

Artificial Intelligence (AI): AI-based solutions improve crop production forecasting, disease and pest identification, and autonomous farming activities (Taneja et al., 2023). Artificial intelligence systems examine satellite photos, soil health data, and climate predictions to improve scheduling of planting and watering tactics.(Ganeshkumar et al., 2023).

Machine Learning (ML): ML algorithms facilitate predictive analytics in agriculture, enabling farmers to anticipate yield outcomes, detect anomalies in crop growth, and optimize resource allocation(Aijaz et al., 2025). ML-based automation enhances precision farming, where autonomous machinery performs sowing, fertilization, and farming with minimum human intervention (Aijaz et al., 2025).

Internet of Things (IoT): IoT sensors offer farmers the ability to make informed judgments regarding irrigation and fertilization by providing real-time data on soil moisture, temperature, water, and nutrient levels (Shahab et al., 2024). IoT is also critical in smart supply chain management through tracking agricultural produce from farm to market, providing quality assurance, and reducing post-harvest losses (Jararweh et al., 2023).

Integrating these technologies enables Agriculture 4.0, a revolution that utilizes digital technology for precision agriculture, automation, and sustainability (Araújo et al., 2023). The use of ML, IoT, and AI provides a data-driven environment that reduces wastage, improves efficiency, and guarantees food safety for generations to come (Pandey & Mishra, 2024).

SCOPE AND KEY OBJECTIVES OF THE REVIEWS

The primary objective of this review is to explore the revolutionary impact of AI, ML, and IoT in agribusiness by looking into current trends, key challenges, and future perspectives. In particular, this paper aims to:

- Examine the impact of ML, AI and IoT on current agribusiness, including precision farming, smart irrigation, and supply chain management.
- Identify key barriers to the wider use of these technologies, such as high installation costs, data security concerns, and limited technical competence.
- Emphasize recent developments and rising trends in AI-driven agriculture like edge computing, robots, and blockchain integration.
- Offer policy recommendations for sustainable and scalable deployment of ML, AI and IoT in agribusiness.

This review synthesizes information from multiple research articles to present a comprehensive overview of digital transformation in agriculture. By addressing both potential and problems, the study hopes to provide significant insights for officials, researchers and agribusiness partners.

The Role of AI and ML in Agribusiness

AI and ML Applications in Precision Farming

The application of Machine Learning (ML) and Artificial Intelligence (AI) in precision agriculture has greatly impacted the agriculture practice by enhancing decision-making, resource utilization efficiency, and productivity. AI methods use data sources, i.e., satellite images, IoT sensors, and past agricultural data, to achieve maximum efficiency and sustainability (Aarif K. O. et al., 2025). These tools automate farm operations, preliminary identification of crop stress, and predictive analytics, thereby reducing labour-intensive activities while increasing overall farm efficiency (Ahmed et al., 2024).

AI-driven autonomous equipment, such as autonomous harvesters and autonomous tractors, has also further increased efficiency by minimizing human control and labor expense (Chataut et al., 2023). To guarantee optimal use of water and fertilizers, artificial intelligence systems have also been combined with drones to offer real-time monitoring of soil moisture levels and crop health (Schaefer, 2023).

Yield Prediction and Crop Management

AI and ML models are essential in crop management and yield forecasting through the analysis of soil health, climate trends, and plant growth phases. For example, ML algorithms like deep learning models and artificial neural networks (ANNs) are employed to forecast cro

p yields using past data and current environmental conditions (Ahmed et al., 2024; Duguma & Bai, 2024).

More advanced data combination methods integrating IoT and ML enhanced yield prediction precision, enabling farmers to better tailor planting schedules and resource allocation (Chataut et al., 2023). Multispectral imaging technologies deployed from drones coupled with ML models have shown immense success in monitoring plant conditions and forecasting yield outputs, which alert farmers regarding prospective yield deficits through environmental factors at an early stage (Schaefer, 2023; Duguma & Bai, 2024).

Disease Detection and Pest Control Optimization

ML-based image processing methods and AI-based sensor networks have improved disease detection and pest control in agriculture. Plant diseases from leaf photos captured by drones or mobile apps are identified using computer vision and deep learning models using convolutional neural networks (CNNs). (Adli et al., 2023; Rugji et al., 2024).

Real-time data-driven AI-based systems such as Plantix and Trace Genomics diagnose soil shortages and disease attacks, which make it possible to have exact intervention measures to limit crop damage (Ahmed et al., 2024). Moreover, robotic sprayers coupled with AI help in the controlled application of pesticides, limiting chemical usage and the damage it inflicts on the environment (Aarif K. O. et al.., 2025; Duguma & Bai, 2024).

Predictive Analytics for Irrigation and Resource Allocation

Artificial intelligence-driven predictive analytics have revolutionized irrigation management through the utilization of real-time data from crop models, meteorological stations, and soil moisture sensors. Reinforcement learning and Markov Decision Processes (MDPs) algorithms have been used to automate irrigation schedules in a way that minimizes water usage without compromising the well-being of crops (Aijaz et al., 2025; Mohyuddin et al., 2024).

ML algorithms can estimate seasonal water needs, avoiding both over-irrigation and shortage of water (Chataut et al., 2023; Xi et al., 2022). Automated decision-making is facilitated through smart irrigation systems coupled with IoT, promoting considerable resource savings and increased sustainability in using water (Ahmed et al., 2024; Duguma & Bai, 2024).

The main application areas of AI, ML, and IoT in agribusiness are summarized in Table 1 below, along with the particular methods employed, their advantages, and pertinent references. **Figure 1** illustrates the AI-driven agribusiness workflow, highlighting key steps from data collection and pre-processing to AI model optimization, recommendation generation, and continuous monitoring for improved agricultural outcomes.

The IoT, or Internet of Things, is a disruptive technology in today's agribusiness world that providing stakeholders with near real-time monitoring and automation while leading to data-driven decisions. IoT technology in agriculture utilizes a constellation of smart devices, actuators, and sensors working together to increase resource-use efficiency, decrease waste, and expand efficiency (Chataut et al., 2023; Duguma & Bai, 2024). These smart technologies also utilize predictive analytics using machine learning (ML) and artificial intelligence (AI)

, real-time adjustments, and increase sustainability (Ahmed et al., 2024; Rugji et al., 2024).

In real time Environmental and Soil Condition Monitoring

Soil monitoring and data analysis including soil moisture, temperature, humidity, and nutrient levels—will be done using wireless sensor networks (WSNs), as part of IoT-based environmental monitoring. Farmers can choose wisely on irrigation, fertilizer, and crop management thanks to the wireless sensors' real-time data transmission to a cloud-based platform. (Aarif K. . et al., 2025; Mowla et al., 2023).

- Smart soil sensors measure pH levels, salinity, and moisture, ensuring optimal growth conditions and reducing unnecessary water usage(Duguma & Bai, 2024).
- IoT-driven climate monitoring systems track temperature fluctuations and extreme weather patterns, enabling early warnings for frost, droughts, and storms (Rehman et al., 2024).
- Real-time monitoring reduces input costs by optimizing pesticide and fertilizer applications, minimizing environmental impact (Ahmed et al., 2024).

IoT-enabled Farm Equipment and Automation

IoT-enabled automation is revolutionizing traditional farm operations by integrating sensors, robotics, and AI-based decision support systems. Intelligent farm equipment, such as autonomous tractors, robotic harvesters, and autonomous irrigation, increases efficiency and productivity (Adli et al., 2023; Schaefer, 2023).

- **Autonomous Tractors:** GPS-enabled, AI-powered tractors perform precision plowing, planting, and harvesting with minimal human intervention, improving productivity (Chataut et al., 2023).
- **Drone Technology:** Multispectral and thermal imaging-equipped drones track crop health, detect nutrient deficiencies, and optimize pesticide use (Mesías-Ruiz et al., 2023).
- **Smart Greenhouses:** IoT-greenhouse systems with integrated control manipulate to maximize plant development, use temperature, humidity, and CO_2 levels; this will conserve energy (Aarif K. O. et al., 2025; Mowla et al., 2023).

Logistics Optimization and Supply Chain Management

Through tracking in real time of of produce, decreasing post-harvest losses, and ensuring food safety, IoT has an important part to perform in enhancing agricultural supply chains (Ahmed et al., 2024; Rugji et al., 2024).

- **Smart Sensors in Storage Facilities:** Food quality is maintained and rotting is avoided via IoT-based monitoring of storage parameters like temperature and humidity (Rehman et al., 2024).
- **Blockchain Integration:** IoT-enabled blockchain technologies assist stakeholders confirm the quality and authenticity of produce by ensuring food supply chain transparency and traceability (Chataut et al., 2023).
- **Fleet Management Systems:** GPS and RFID-based IoT solutions optimize logistics by tracking transport routes, reducing delays, and improving delivery efficiency(Duguma & Bai, 2024).

Intelligent Water Management and Systems of Irrigation

Smart irrigation systems enhance water use by use of IoT and artificial intelligence, guaranteeing effective irrigation while preserving resources (Adli et al., 2023).

- **Accurate Irrigation:** IoT-enabled soil moisture sensors assess real-time water needs and automate irrigation schedules, reducing water wastage by up to 30% ((Aarif K. O. et al., 2025; Duguma & Bai, 2024).
- **Drip Irrigation Control Systems:** By providing water directly to the roots of plants, IoT-based Drip watering lowers runoff and increases water use efficiency (Mesías-Ruiz et al., 2023).

- **AI-driven Forecasting:** In order to forecast drought conditions and optimize irrigation planning, AI-powered algorithms examine both historical and current weather data (Rehman et al., 2024).

Integration of IoT with AI for Decision Support

IoT combined with AI and ML improves decision-making skills, enabling automation and predictive analytics in agribusiness (Ahmed et al., 2024; Duguma & Bai, 2024).

- **AI-Powered Data Analytics:** In order to forecast agricultural productivity, improve resource allocation, and identify diseases early, machine learning algorithms evaluate sensor data (Schaefer, 2023).
- **Automated Decision Support Systems:** Farm production is increased by AI-driven platforms that offer real-time advice on irrigation, pest, fertilizer, and herbicide management (Rehman et al., 2024; Rugji et al., 2024).
- **IoT-Cloud Integration** AI-powered systems increase farm output by offering real-time advice on irrigation, fertilizer, and pest management (Rehman et al., 2024; Rugji et al., 2024).

Table 2 compares traditional farming with IoT-enabled smart farming across key agricultural features, highlighting advancements in monitoring, equipment, supply chain management, irrigation, and decision-making. Relevant references support the comparison.

Figure 2 presents an IoT-enabled smart farming architecture, illustrating the integration of various environmental sensors (for example, soil moisture, temperature, humidity, and light) with a centralized database via a communication network. This data is processed and utilized to control automated systems like irrigation, fans, and pumps, optimizing agricultural efficiency.

Obstacles to AI, ML, and IoT Adoption in Agribusiness

The combination of artificial intelligence (AI), machine learning (ML), and the internet of things (IoT) in agriculture holds revolutionary potential for boosting efficiency, sustainability, and productivity However, a number of obstacles, including high implementation costs, technological complexity, and data security, are slowing adoption, and regulatory issues (Ahmed et al., 2024; Duguma & Bai, 2024). These can be overcome through concerted efforts between policymakers, scientists, and agribusiness actors to create scalable and sustainable solutions.

High startup costs and worries about return on investment

Perhaps the biggest challenge facing AI, ML, and IoT applications in agriculture is the initial capital outlay of implementation. Devices like precision agriculture sensors, drones, autonomous machines, and analytics platforms powered by AI are quite expensive to deploy, and for small and medium-scale farmers, they are financially out of reach (Chataut et al., 2023; Mowla et al., 2023).

- **Smart Equipment Price:** Smart farm equipment, such as robotic harvesters and self-driving tractors, is still costly, ranging from $50,000 to more than $500,000 based on applications and functionality (Rehman et al., 2024).
- **Return on Investment (ROI) Concerns:** Most farmers doubt the profitability of AI-based systems due to short-term uncertainties in profits and non-instant cost recovery (Aarif K. O. et al., 2025).
- **Financial Assistance Gaps:** Lack of access to government subsidies, low-interest loans, and fiscal incentives further constrains adoption in particularly in developing nations, small-scale farmers (Adli et al., 2023; Ahmed et al., 2024).

Barriers to training and a lack of technical expertise

Successful deployment of AI, ML, and IoT in agribusiness calls for technical know-how and expertise, which is not possessed by most farmers and agribusiness experts (Duguma & Bai, 2024).

- **Skill Gap in AI & IoT Usage:** Most farmers lack knowledge of AI-based decision tools, predictive analytics, and IoT sensor calibration (Chataut et al., 2023).
- **Limited Training Programs:** The number of structured AI and IoT training programs for farmers is low, especially in rural areas (Mowla et al., 2023).
- **Lack of Digital Literacy:** Many smallholder farmers **lack digital literacy**, making it challenging for them to communicate with intelligent farming systems (Rehman et al., 2024).

Data Privacy and Security Issues in Precision Agriculture

AI, ML, and IoT produce an enormous volume of data, comprising real-time conditions of the farms, crop health indicators, and financial data, which pose strong privacy issues (Adli et al., 2023; Ahmed et al., 2024).

- **Cybersecurity Risks:** IoT networks are vulnerable to **cyberattacks**, data breaches, and hacking attempts, which can lead to the **manipulation of farming operations** (Rehman et al., 2024).
- **Ownership of Agricultural Data:** There is ambiguity over **who owns and controls farm-generated data**, leading to concerns over potential **misuse by tech firms** (Aarif K. O. et al., 2025).
- **Weak Regulatory Frameworks:** Many **developing countries lack strict data protection laws**, making agricultural data susceptible to **unauthorized third-party access** (Rugji et al., 2024).

Infrastructure Challenges in Rural and Remote Areas

The adoption of AI and IoT-based solutions is hampered by the lack of adequate digital infrastructure in rural areas, where agriculture is the primary industry (Mesías-Ruiz et al., 2023).

- **Limited Internet Connectivity:** Many farms lack access to **high-speed broadband**, restricting the functionality of **IoT-based smart farming systems**(Duguma & Bai, 2024).
- **Unreliable Power Supply:** Frequent power outages make it difficult to maintain continuous **sensor-based monitoring** and **AI-driven automation** (Rehman et al., 2024).
- **High Cost of Connectivity:** Deploying **5G-enabled smart agriculture** is expensive and often impractical in **low-income farming communities** (Ahmed et al., 2024).

Ethical and Regulatory Considerations

AI, ML, and IoT in agriculture raise ethical concerns regarding **data transparency, automation, and job displacement**(Ahmed et al., 2024).

- **Farmer Autonomy:** Heavy reliance on **AI-driven decision-making** may reduce farmers' control over **their own agricultural practices**(Duguma & Bai, 2024).
- **Job Displacement:** Automation of farm tasks threatens **traditional agricultural jobs**, creating **socioeconomic challenges** in rural areas (Duguma & Bai, 2024).
- **Lack of Standardized Regulations:** Many countries **lack clear policies** on the ethical applications of AI for agricultural purposes, leading to **inconsistent implementation**(Adli et al., 2023).

Table 3 outlines key challenges in adopting AI, ML, and IoT in agribusiness along with potential solutions, supported by relevant references. The table highlights strategies to mitigate high costs, technical skill gaps, data security risks, infrastructure limitations, and ethical concerns.

Future Directions and Research Opportunities

Agribusiness is constantly changing due to the quick development of Combining artificial intelligence (AI), machine learning (ML), and the internet of things (IoT), which is paving the way for data-driven, highly automated, and sustainable farming methods. Future studies will concentrate on improving AI algorithms, utilizing Using blockchain technology to increase supply chain transparency, edge computing to make decisions in real time, and developing robotics for autonomous farming (Ahmed et al., 2024; Duguma & Bai, 2024). Additionally, policy frameworks must evolve to support large-scale AI and IoT adoption, ensuring ethical, economic, and infrastructural considerations are addressed (Chataut et al., 2023; Rehman et al., 2024).

AI and ML Developments for Sustainable Agriculture

AI and ML applications in agriculture will expand significantly, focusing on sustainability, resource efficiency, and climate resilience. Future AI models will be trained on larger, more diverse datasets, enabling more precise crop yield predictions, disease detection, and climate-adaptive farming(Aarif K. O. et al., 2025; Chataut et al., 2023).

- AI-enhanced soil health monitoring will utilize hyperspectral imaging, real-time sensor networks, and ML models to assess soil composition, detect nutrient deficiencies, and recommend optimized fertilization strategies (Mowla et al., 2023; Rugji et al., 2024).
- DL models will improve pest and disease identification by analysing large datasets of high-resolution images from drones, satellites, and farm cameras (Mesías-Ruiz et al., 2023; Ahmed et al., 2024)
- AI-driven climate prediction models will leverage historical meteorological data, IoT sensor inputs, and real-time satellite imagery to forecast droughts, floods, and extreme weather conditions (Duguma & Bai, 2024; Rehman et al., 2024).
- AI-integrated smart irrigation will enhance water conservation strategies by dynamically modifying watering plans in response to real-time environmental data(Duguma & Bai, 2024).

Future studies must concentrate on enhancing the effectiveness, precision, and usability of AI-powered precision agricultural instruments, making them affordable and scalable for smallholder farmers in developing regions (Adli et al., 2023; Chataut et al., 2023)

Blockchain Integration for Supply Chain Transparency

Blockchain technology will play an increasingly critical role in ensuring food traceability, improving supply chain efficiency, and reducing fraud in agribusiness (Ahmed et al., 2024; Rehman et al., 2024). Including tracking systems according to the IOT with blockchain Real-time monitoring will be made possible by networks of agricultural products, from production to retail.

- Smart contracts in blockchain will automate payments, compliance verification, and supply chain transactions, reducing inefficiencies in logistics and distribution (Chataut et al., 2023; Duguma & Bai, 2024).
- In order to address concerns about food fraud and contamination, farmers, retailers, and consumers will be able to determine the source, quality, and food product safety through the integration of IoT-based tracking systems ii. End-to-end traceability (Aarif K. O. et al., 2025; Rugji et al., 2024).
- Decentralized data management will enhance cybersecurity and prevent unauthorized

modifications to supply chain records, ensuring trustworthy digital documentation (Mowla et al., 2023; Mesías-Ruiz et al., 2023).

- Blockchain-powered carbon credit tracking will allow sustainable farming initiatives to be rewarded through verified carbon offset programs, promoting eco-friendly practices (Adli et al., 2023).

This field's research will concentrate on improving blockchain scalability, transaction speeds, and interoperability with IoT systems, ensuring widespread adoption across global food supply chains (Ahmed et al., 2024; Duguma & Bai, 2024).

Edge Computing and 5G for Enhancing IoT Efficiency

By enhancing real-time decision-making and cutting down on data transmission delays, edge computing and 5G networks will transform Smart agriculture with IoT apps (Chataut et al., 2023;)

- Edge AI models will process real-time IoT sensor data locally, reducing dependency on cloud computing and improving system responsiveness for automated decision-making in accurate farming (Ahmed et al., 2024; Rehman et al., 2024).
- 5G-enabled smart farms will support high-speed data transfer between IoT sensors, drones, and robotic farming equipment, enabling seamless automation and monitoring (Aarif K. O. et al., 2025; Mowla et al., 2023).
- Low-latency AI-powered crop management systems will analyze multispectral satellite imagery and environmental data in real-time, optimizing yield prediction and precision irrigation (Rufji et al., 2024; Mesías-Ruiz et al., 2023).
- Edge-based pest detection systems will use AI algorithms to identify crop diseases and apply targeted treatments automatically, reducing pesticide overuse(Adli et al., 2023; Ahmed et al., 2024).

Additional investigation is necessary to optimize 5G and edge computing infrastructure in rural and remote farming areas, ensuring affordable and efficient deployment (Duguma & Bai, 2024; Rehman et al., 2024).

AI-driven Autonomous Farming Systems and Robotics

Autonomous farming technologies will continue to evolve, enabling fully automated, AI-driven farming systems that optimize productivity and labor efficiency (Aarif K. O. et al., 2025; Ahmed et al., 2024).

- AI-powered autonomous tractors will improve land preparation, seeding, and harvesting, reducing dependency on manual labor (Duguma & Bai, 2024; Rehman et al., 2024).
- Drone-based robotic farming will expand, with AI-enhanced drones monitoring crop health, applying fertilizers, and detecting irrigation needs with pinpoint accuracy (Chataut et al., 2023; Mesías-Ruiz et al., 2023).
- Autonomous weed control systems will use Machine Learning and Computer vision models to identify and eliminate weeds without chemical herbicides, promoting sustainable agriculture (Mowla et al., 2023; Rugji et al., 2024).
- Autonomous irrigation robots will integrate IoT, AI, and ML to improve crop health, reduce water waste, and maximize water distribution (Adli et al., 2023; Ahmed et al., 2024).

Future research must focus on cost reduction, energy this field's research will concentrate on with existing agricultural machinery, ensuring scalable and affordable deployment(Duguma & Bai, 2024).

Policy Recommendations for Wider Adoption and Scalability

To ensure widespread adoption of AI, ML, and IoT in agribusiness, governments and international organizations must develop robust policy frameworks that address infrastructure challenges, digital equity, and ethical considerations(Ahmed et al., 2024; Chataut et al., 2023).

- Regulations on AI-driven agricultural automation must balance technological progress with labor market stability, ensuring inclusive economic growth (Duguma & Bai, 2024; Rehman et al., 2024).
- Data privacy laws for smart agriculture must be standardized to prevent unauthorized access and misuse of farm-generated data (Mowla et al., 2023; Rugji et al., 2024).
- Sustainability policies should incentivize eco-friendly AI applications, promoting low-carbon, resource-efficient farming practices (Aarif K. O. et al., 2025; Adli et al., 2023).

Figure 3 presents a future roadmap of of IoT, AI, and ML is changing agribusiness, depicting the progressive convergence of advanced technologies in agriculture from 2025 to 2035. The timeline highlights key innovations, including AI-driven precision farming, IoT-based smart irrigation, autonomous agricultural robotics, and AI-powered supply chain optimization. Each milestone represents a significant advancement aimed at enhancing crop yield, resource efficiency, automation, and supply chain transparency. The roadmap visually connects these developments with a dashed line, illustrating the continuous evolution of smart farming technologies toward a healthier and productive agricultural system.

CONCLUSION

The convergence of IoT, AI, and ML is changing agribusiness by increasing efficiency, sustainability, and productivity while challenges like high cost of implementation, technical skill gaps, data security issues, and rural infrastructure constraints continue to exist.

This review underlined major trends and opportunities such as precision farming, where artificial intelligence-based models improve crop yield forecasts, disease identification, and intelligent irrigation; IoT-based smart agriculture that provides real-time tracking to enhance decision-making and input wastage minimization; supply chain optimization by integrating blockchain technology for enhanced food traceability and logistics optimization; automation through AI-based robotics minimizing labor dependency; and advances in technology such as edge computing, and 5G that enable quicker data processing and enhanced connectivity in far-flung areas.

The stakeholder implications are diverse: farmers can gain from lower costs and higher yields through AI analysis and IoT sensors, but these technologies need proper technical training and infrastructure; agribusiness firms can benefit from enhanced supply chain management and customized, affordable technology solutions; policymakers and governments need to prioritize infrastructure development, digital literacy, and balanced regulatory environments; and researchers are invited to spearhead innovations in sustainable farming paradigms and scalable technology integrations.

Overcoming these obstacles will involve a collaborative effort on the part of farmers, technology companies, policymakers, and researchers to set the stage for the complete fulfilment of AI, ML, and IoT's revolutionary potential in agribusiness for a sustainable future.

Table 1: Summary of AI and ML Applications in Agriculture

Application Area	AI/ML Techniques Used	Benefits	References
Precision Farming	IoT, Data Fusion, AI-driven Decision Support.	Optimized resource use, increased efficiency.	(Aarif K. O. et al., 2025; Duguma & Bai, 2024).
Yield Prediction	Deep Learning, ANN, Remote Sensing.	Accurate forecasting, improved planning.	(Ahmed et al., 2024; Chataut et al., 2023).
Disease Detection	Computer Vision, CNNs, Image Analysis.	Targeted interventions and early diagnosis.	(Adli et al., 2023; Rugji et al., 2024).
Irrigation Management	Reinforcement Learning, IoT-based AI.	Water conservation, efficient irrigation scheduling.	(Aijaz et al., 2025; Mohyuddin et al., 2024).
Productivity Enhancement	AI Robotics, Supply Chain AI.	Cost reduction, labor efficiency.	(Aarif K. O. et al., 2025; Ahmed et al., 2024).

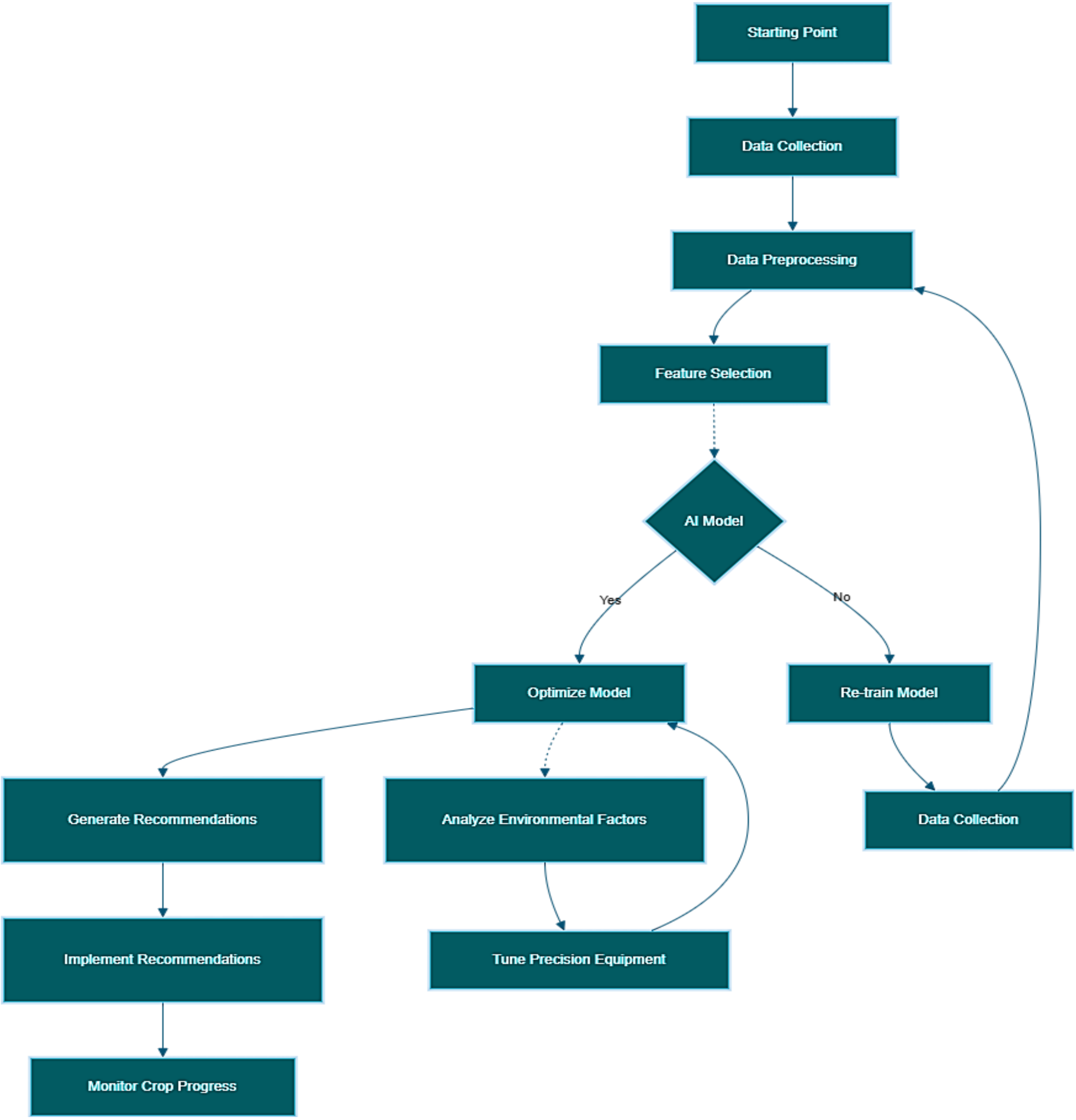

Figure 1: AI-Driven Precision Farming Process Flow

Table 2: Comparison of Traditional Farming vs. IoT-enabled Smart Farming

Feature	Traditional Farming	IoT-enabled Smart Farming	References
Monitoring	Manual inspection, time-consuming	Real-time sensor-based monitoring	(Aarif K. O. et al., 2025; Duguma & Bai, 2024)
Equipment	Conventional tractors, manual labor	AI-driven autonomous machinery & robotics	(Adli et al., 2023; Ahmed et al., 2024)
Supply Chain	Inefficient logistics, high post-harvest losses	IoT tracking, blockchain-based transparency	(Chataut et al., 2023; Rugji et al., 2024)
Irrigation	Fixed schedules, excessive water use	Smart irrigation, AI-based forecasting	(Duguma & Bai, 2024; Mowla et al., 2023)
Decision Making	Experience-based, error-prone	AI-driven predictive analytics	(Ahmed et al., 2024; Schaefer, 2023)

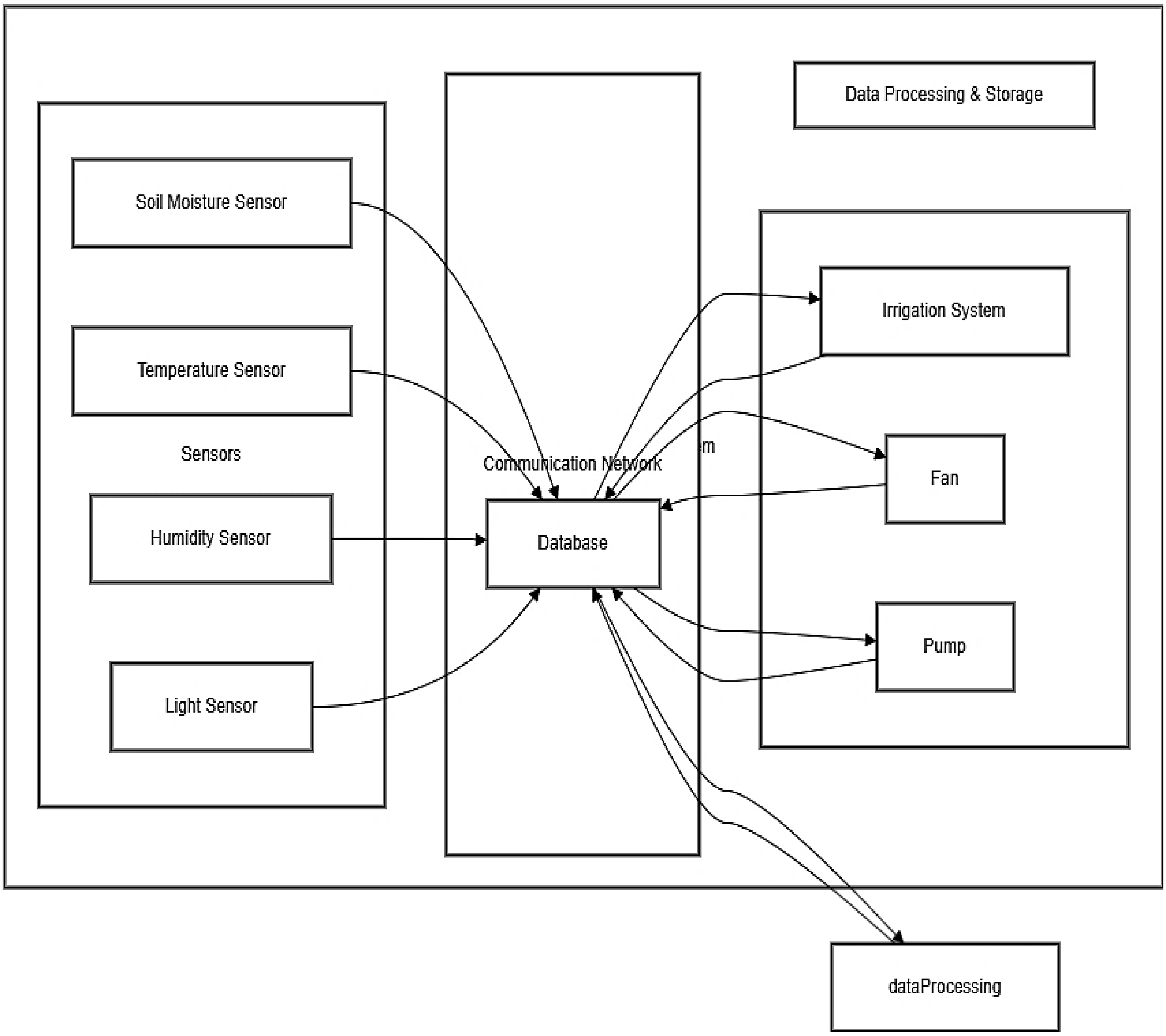

Figure 2: An IoT-based smart agriculture system's architecture.

Table 3: Key Challenges in AI, ML, and IoT Adoption in Agriculture and Potential Solutions

Challenge	Potential Solution	References
High initial investment	Government subsidies, Artificial intelligence as a Service Models.	(Ahmed et al., 2024; Duguma & Bai, 2024)
Lack of technical skills	AI training programs, user-friendly applications	(Chataut et al., 2023; Duguma & Bai, 2024)
Data security risks	Blockchain for secure data management	(Rehman et al., 2024; Rugji et al., 2024)
Rural infrastructure gaps	Expansion of broadband and solar-powered IoT	(Aarif K. O. et al., 2025; Mowla et al., 2023)
Ethical concerns	AI governance frameworks and policy standards	(Adli et al., 2023; Ahmed et al., 2024)

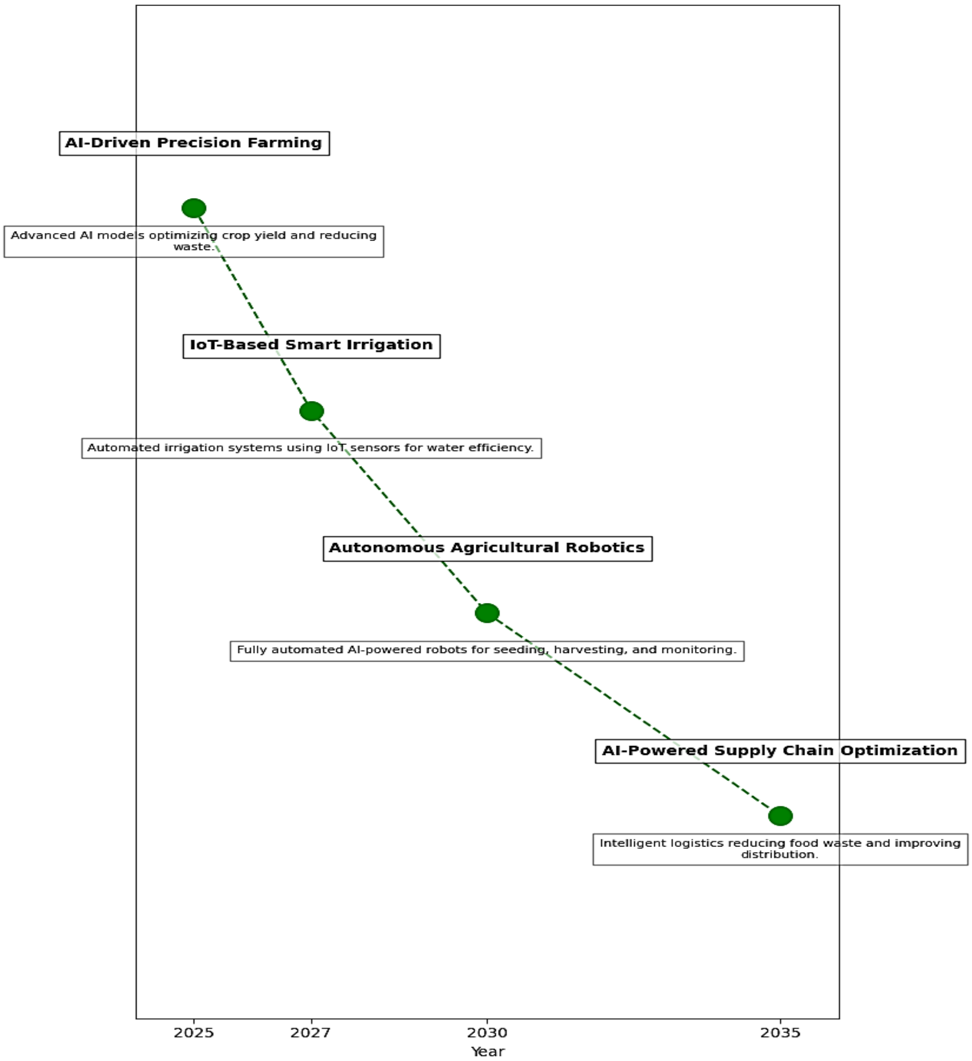

Figure 3: Future roadmap of AI, ML, and IoT in agribusiness.

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