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AI and IoT for Precision Farming: Transforming Indian Agriculture

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Abstract

Agriculture plays a crucial role in the global economy with the exponential rise in population. There is a parallel increase in the demand for food and employment exerting pressure on conventional farming methods. These traditional techniques are often inadequate in meeting current agricultural demands. Consequently, automation in agriculture has gained significant attention as an evolving field. The integration of artificial intelligence (AI) into agricultural processes has led to a transformative shift enhancing crop productivity while mitigating challenges such as climate change, labour shortages and food security concerns. This study presents a comprehensive review of AI-enabled applications in agriculture including automated irrigation, precision spraying, and weeding systems, implemented through sensors, robotics and unmanned aerial vehicles UAVs. These technologies aid in optimizing water usage, minimizing the overuse of pesticides and herbicides, maintaining soil fertility and improving labour efficiency. The review further examines contemporary research on robotic and drone-based weeding systems, soil moisture sensing approaches, and UAV-assisted spraying and crop-monitoring techniques.

Keywords: Precision farming, artificial intelligence, internet of things, Indian agriculture, smart agriculture, sustainability, automation

INTRODUCTION

Long-term viability and ecological compatibility in grain production practices are characteristics of sustainable agriculture. Sustainable agriculture promotes practices and strategies that are advantageous to both human and natural resource long-term existence. It is practical from a financial standpoint, and it protects the quality of the soil, slows down the rate at which the soil degrades, conserves water resources, increases the biodiversity of the land, and guarantees a healthy and natural atmosphere. The practice of sustainable farming plays a vital role in the protection of natural resources, the slowing of the loss of biodiversity, and the reduction of greenhouse gas emissions. A method for preserving the environment without compromising the ability of future generations to meet their basic needs is called "sustainable agriculture". In addition, it is a technique for making farming more efficient. Sustainable agriculture is largely attributable to the central success of intelligent farming, which includes harvest alteration, the management of nutrient deficits in crops, the control of pests and diseases, recycling, and water harvesting. These accomplishments lead to an overall safer world. However, an ever-expanding worldwide population with increased hunger, rapidly changing climate conditions, overuse of resources, and wastage of food and water are obscuring the effect of sustainable agriculture. The need of time is to develop technologies and infrastructure capable of meeting the demands of the present as well as the future. Technological innovations have always been the fundamental means for the development of agriculture, from the

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pre-historic era to today, as illustrated in Figure 1. Breakthroughs like the development of simple tools and the utilization of animals; the use of fertilizers, pesticides, and small machinery; and the application of robots helped agriculture evolve to its present status, and now, with the use of smart technology, agriculture is impending to become smart.

The diagram illustrates the evolution of agriculture through four distinct eras, each marked by technological advancements and changes in farming practices. Let us break down each era:

Agriculture 1.0 (10,000 BC)

- *Ancillary Aspects:* This era depicts the early stages of agriculture when humans began cultivating crops.
- *Strategic Features:* Primarily relied on simple tools, manual labour, and animal power for farming activities.

Agriculture 2.0 (19th Century)

- *Ancillary Aspects:* This era witnessed the advent of the Industrial Revolution, leading to significant advancements in agriculture.
- *Strategic Features:* Introduction of steam engines, chemical fertilizers, and agricultural machinery like tractors revolutionized farming practices, increasing efficiency and productivity.

Agriculture 3.0 (20th Century)

- *Ancillary Aspects:* This era saw the integration of computers and robotics into agriculture.
- *Strategic Features:* Utilization of robots and computer programs for tasks like precision planting, automated harvesting, and data analysis.

Agriculture 4.0 (Today)

- *Ancillary Aspects:* The current era is characterized by the convergence of technologies like the Internet of Things (IoT), Big Data, Cloud Computing, and Artificial Intelligence (AI).
- *Strategic Features:* Prioritizing data-driven decision-making, smart devices, and smart systems to maximize resource utilization, boost output, and guarantee sustainability.

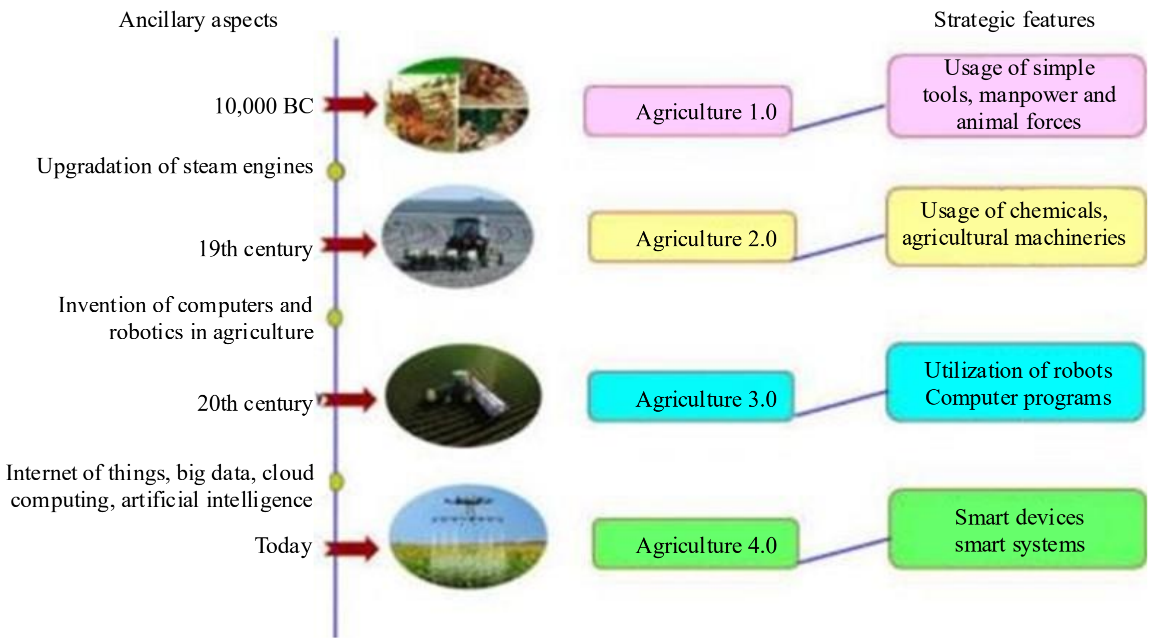

Figure 1. Indicates the upgradation of agriculture.

Smart farming has become an important component of sustainable agriculture [1]. Traditionally, a huge amount of time, money, and effort is invested in growing any crop. It is worth mentioning the time and effort required in the processing, transportation, and marketing of harvested crops and all other logistics associated with them. Technologies of smart farming present a way to deal with and alleviate these problems, offering an improved way of doing agro-businesses. Agriculture is the sector that contributes the most to India’s GDP, accounting for 18% of the country’s total and employing around 57% of the population in rural regions. Despite the fact that India's total agronomic output has increased over time, the proportion of growers has fallen from 71.9% in 1951 to 45.1% in 2011. This deterioration took place over the course of the nation's history. The Economic Survey for 2018 found that the percentage of the entire employment that is comprised of agricultural employees would fall to 25.7% in the year 2050. In rural places, agricultural families progressively lose the next generation of farmers as they are overwhelmed by the increased expenses of agriculture, poor per capita production, insufficient soil upkeep, and migrations to occupations that are either non-farming or better paying than farming [2]. The globe is on the edge of a technological age; therefore, now is the time to connect the agricultural landscape with wireless technology to facilitate digital interaction among farmers. Agricultural landforms are characterised by large areas of open space. IoT and AI will assist companies in becoming more productive, reducing the amount of waste they create, and satisfying the need for food that customers have. Based on the findings of a number of studies, it has been determined that AI and IoT have a wide range of potential applications within the agricultural sector, as illustrated in Figure 2.

This highlights, as the diagram focuses on, how IoT technologies are being used to enhance agricultural practices.

Specific Applications

Drones for Agriculture

The drones that can operate both on the ground and in the air can help in the evaluation of crop health, the monitoring of infestations, and the examination of soil more efficiently.

Figure 2. IoT for smart agriculture.

In addition, they may be used for the collection of real-time field data, the sowing of seeds, the management of irrigation systems, and the spraying of crops [3]. The data collected could be utilized to map external effects, assess nutrient levels, and forecast production.

Farm Monitoring

To keep an eye on variables like soil moisture, temperature, humidity, and nutrient levels, IoT sensors can be placed across the farm. Pest management, fertilization, and irrigation can all be improved with the help of this data.

Accurate farming

Precision farming is among the most popular uses of agricultural technology. It offers services like cloud-based centralized water management, soil moisture measurement, and variable rate irrigation (VRI) optimization. The system efficiently uses the water resource by utilizing sensors, self-sufficient equipment, and an internet connection.

Monitoring and Tracing

IoT may be used to monitor and trace agricultural items' movements across the supply chain, guaranteeing the quality and safety of food.

Intelligent Weather Tracking

Farmers may make well-informed decisions regarding planting, harvesting, and irrigation with the use of real-time, reliable meteorological data from IoT-based weather stations.

Livestock Monitoring

Temperature, heart rate, and location are just a few of the health and welfare indicators that may be tracked by IoT devices. This data can help farmers identify sick animals early and improve overall herd health.

IoT Smart Greenhouses

IoT can be used to control environmental conditions within greenhouses, such as temperature, humidity, and lighting, optimizing plant growth and yield.

Analytic Data and Prediction

AI and machine learning algorithms can be used to analyse IoT data in order to forecast crop yields, spot possible hazards, and improve farm management techniques.

CASE STUDIES

Case Study: Maharashtra's Accurate Watering Context

Maharashtra faces a serious water shortage, particularly during the dry season. Farmers frequently use conventional irrigation techniques, which wastes water and lowers agricultural yields.

- *Resolution:* In Maharashtra, an Internet of Things-based irrigation system was put into place as a demonstration project. In the fields, soil moisture sensors were positioned and linked to a cloud platform. To improve irrigation schedules, AI algorithms analysed sensor data, crop requirements, and weather forecasts.
- *Impact:* Using this technique allowed farmers to maintain or even increase crop yields while reducing water use by 20–30%. The labour expenses related to manual irrigation were also decreased by the method.

Case Study: Disease Detection in Karnataka

- *Context:* Coffee plantations in Karnataka are susceptible to various diseases, leading to significant yield losses.
- *Solution:* An AI-powered image recognition system was developed to detect coffee leaf rust, a major disease affecting coffee plants. Farmers can capture images of coffee leaves using their

smartphones and upload them to the cloud. The AI model analyses the images and identifies the presence of the disease with high accuracy.
- *Impact:* Early detection of coffee leaf rust allows farmers to take timely action, such as applying fungicides, thereby minimizing crop losses. The system has helped reduce the use of pesticides and improved the overall health of coffee plantations.

Case Study: Livestock Monitoring in Gujarat
- *Context:* Dairy farming is a significant contributor to the rural economy in Gujarat. However, monitoring the health and well-being of livestock can be challenging.
- *Solution:* An IoT-based livestock monitoring system was implemented in Gujarat. Each cow was fitted with a smart collar equipped with sensors to monitor vital parameters like temperature, heart rate, and activity levels. The data was transmitted to a central platform where AI algorithms analysed the information to identify signs of illness or stress.
- *Impact:* The system helped farmers detect health issues in cattle early, leading to timely veterinary interventions and improved animal health. This resulted in increased milk production and reduced mortality rates, improving the profitability of dairy farms.

LITERATURE REVIEW

AI in Agriculture

AI algorithms, including machine learning (ML), deep learning, and computer vision, are being increasingly employed in various agricultural applications. In order to forecast future events and maximize resource allocation, machine learning algorithms analyse past data on crop yields, soil conditions, and weather patterns [4]. Convolutional neural networks (CNNs), a type of deep learning approach, have demonstrated encouraging outcomes in picture recognition for tasks including weed identification and illness detection [5]. Aerial and satellite imagery can be analysed using computer vision algorithms to evaluate crop health, track field conditions, and improve watering schedules [6].

IoT in Agriculture

IoT technologies, such as sensors, actuators, and communication networks, play a crucial role in enabling data-driven decision-making in agriculture. IoT sensors gather data in real time on a number of variables, including temperature, humidity, nutrient levels, and soil moisture. This information is sent to a central platform for analysis and used in improving pest control, fertilization, and irrigation [7]. IoT-enabled devices, such as drones and robots, are also being used for tasks like crop monitoring, precision spraying, and automated harvesting [8].

AI and IoT Integration

The integration of AI and IoT technologies is crucial for realizing the full potential of precision agriculture. IoT devices provide enormous volumes of data, which AI systems can analyse to glean insightful information and help with decision-making. AI algorithms, for example, may analyse sensor data to forecast crop production, identify irregularities, and instantly improve resource allocation [9]. The combination of AI and IoT enables the development of intelligent systems that can adapt to changing environmental conditions and optimize agricultural practices dynamically [10].

Challenges and Opportunities

Despite the significant potential of AI and IoT, several challenges hinder their widespread adoption in Indian agriculture. These include:
- *Expensive initial outlay of funds:* One of the biggest obstacles for smallholder farmers may be the expense of purchasing and deploying AI and IoT devices.
- *Low level of digital literacy:* The digital literacy needed to use and understand data produced by AI and IoT technologies is often lacking among farmers.
- *Data connectivity issues:* Limited internet connectivity in rural areas can hinder the effective transmission and analysis of data generated by IoT devices.

- *Concerns about data security and privacy:* Security and privacy issues are brought up by the gathering and storing of vast volumes of data.

However, these challenges also present opportunities for innovation. The development of low-cost, user-friendly, and accessible AI and IoT solutions is crucial for increasing adoption among smallholder farmers. Government initiatives, such as digital literacy programs and subsidies for technology adoption, can play a significant role in addressing these challenges.

Future Directions

Future research in AI and IoT for precision farming should focus on:

- Developing more robust and accurate AI models for tasks such as disease prediction, yield forecasting, and resource optimization.
- Enhancing smallholder farmers' access to and affordability of AI and IoT technologies.
- Using strong data protection methods to address concerns about data security and privacy.
- Developing user-friendly interfaces that facilitate the interaction between farmers and AI/IoT systems. Integrating AI and IoT with other emerging technologies, such as blockchain and robotics, to create more comprehensive and sustainable agricultural solutions.

METHODOLOGY

Data Collection

- *Review of Literature:* Using pertinent databases like IEEE Xplore, Scopus, Web of Science, and Google Scholar, a thorough literature review was carried out.
- Keywords used for the search included "precision agriculture", "AI in agriculture", "IoT in agriculture", "Indian agriculture", "smart farming", and combinations thereof. The review focused on academic articles, conference papers, industry reports, and government publications.
- *Case Study Analysis:* In-depth case studies were conducted on specific AI and IoT-based precision farming projects implemented in India. Data collection for the case studies involved:
- *Primary Data:* Interviews with farmers, agricultural extension officers, and project implementers to gather insights on the implementation process, challenges faced, and perceived benefits.
- *Secondary Data:* Collection of relevant data from project reports, government publications, and online databases.

Data Analysis

- *Qualitative Analysis:* Thematic analysis was employed to analyse the qualitative data collected through interviews and case studies. Key themes were identified and categorized to understand the challenges, opportunities, and impacts of AI and IoT in Indian agriculture.
- *Quantitative Analysis:* Where applicable, quantitative data such as yield data, resource usage data, and economic impact data were analysed using statistical methods such as descriptive statistics, regression analysis, and cost-benefit analysis.

Ethical Considerations

- Every person who took part in the interviews gave their informed consent.
- Confidentiality and privacy of the data were maintained during the entire study.
- Every research activity was carried out in compliance with applicable laws and ethical standards.

Findings

The findings of this study reveal several key insights into the implementation and impact of AI and IoT technologies in Indian agriculture (Table 1):

Benefits and Impacts

- *Increased Productivity:* Case studies demonstrated significant increases in crop yields (e.g., 15–20%) through optimized irrigation, precision fertilization, and improved pest management.

- *Enhanced Resource Efficiency:* IoT-enabled systems were found to reduce water consumption by 20–30% while maintaining or even increasing crop yields. Similarly, precision fertilization techniques led to a significant reduction in fertilizer usage, minimizing environmental impact.
- *Improved Farm Profitability:* Farmers who adopted AI and IoT technologies reported increased farm incomes due to higher yields, reduced input costs, and improved market access.
- *Water:* Water consumption in Rajasthan has been reduced by 30% thanks to IoT-based smart irrigation systems. The ministry's copy of Jal Shakti's 2022 report served as the source of this information (Table 2).
- *Fertilizers:* Gujarat has seen a 25% reduction in fertilizer usage through the implementation of AI-powered precision fertilization techniques. This data is attributed to the ICAR (Indian Council of Agricultural Research) 2023 report.
- *Energy:* Adoption of AI-optimized pumping equipment has allowed Karnataka to reduce energy consumption by 18%. The Ministry of Power's 2022 report served as the source of this information.
- *Reduced Input Costs:* The "Average Input Cost (per hectare)" decreased from ₹ 50,000 to 45,000 after AI and IoT adoption, resulting in a net gain of ₹ 5,000/ha. This suggests that technologies like precision irrigation and fertilization are optimizing resource use, leading to cost savings.
- *Increased Yield:* The "Average Yield (per hectare)" increased from 3.5 to 4.2 t, a gain of 0.7 t/ha. This indicates that AI and IoT-driven practices such as optimized planting, pest control, and disease management are contributing to higher crop production.
- *Improved Market Price:* While the "Average Market Price (per ton)" shows a modest increase from ₹ 20,000 to 22,000, this translates to additional revenue for farmers.
- *Significant Profit Increase:* The most striking change is in "Average Profit (per hectare)", which has risen from ₹ 20,000 to 38,000, a substantial gain of ₹18,000. This demonstrates the combined positive impact of reduced costs, increased yield, and improved market prices.
- *Enhanced Food Security:* AI and IoT technology help to improve food security in India by raising agricultural output and lowering post-harvest losses.
- *Improved Decision-Making:* Farmers using AI-powered tools reported improved decision-making capabilities, leading to better planning and risk management.

Challenges and Barriers

- *High Initial Investment Costs:* The high upfront cost of acquiring and implementing AI and IoT Technology remains a significant barrier for smallholder farmers.
- *Digital Proficiency:* Many farmers are not digitally literate enough to use and understand the data produced by AI and IoT systems.

Table 1. The table showcases real-world examples of how AI and IoT technologies are enhancing resource efficiency in Indian agriculture across three key areas.

Resource	Technology Used	State	Savings (%)	Data Source
Water	IoT-Based Automated Irrigation	Rajasthan	30%	Ministry of Jal Shakti, 2022
Fertilizers	AI-Powered Precision Fertilization	Gujarat	25%	ICAR, 2023
Energy	AI-Optimized Pumping Systems	Karnataka	18%	Ministry of Power, 2022

Table 2. The table quantifies the economic impact of adopting AI and IoT technologies in Indian agriculture by comparing key metrics before and after implementation.

Metric	Before Adoption	After Adoption	Net Gain/Loss
Average Input Cost (per hectare)	₹ 50,000	₹ 45,000	₹ –5,000
Average Yield (per hectare)	3.5 t	4.2 t	+0.7 t
Average Market Price (per ton)	₹ 20,000	₹ 22,000	₹ 2,000
Average Profit (per hectare)	₹ 20,000	₹ 38,000	₹ 18,000

- *Connectivity of Data:* A major obstacle to real-time data transmission and processing in rural locations is the lack of internet connectivity.
- *Security and Privacy of Data:* Farmers may be deterred from sharing their data due to privacy and security concerns, which would prevent AI and IoT solutions from being implemented effectively.
- *Absence of Skilled Personnel:* To create, deploy, and support AI and IoT solutions in the agriculture industry, there is a lack of qualified experts in fields like data science, agronomy, and engineering.

Government Policies

Multidisciplinary Cyber Physical Systems (NM-ICPS) is a National Mission being implemented by the Department of Science & Technology (DST). 25 Technology Innovation Hubs (TIHs) in cutting-edge technology verticals have been established nationwide in prestigious institutions of national significance in accordance with the Mission. With the aim of conducting research, translation, and technological development for a variety of technologies, including IoT and AI, three of these TIHs are engaged in the applications of IoT and AI in agriculture, specifically:

AI4ICPS Foundation in technology vertical "Artificial Intelligence and Machine Learning" established at IIT Kharagpur, TIH Foundation of IOT and Internet of Everything (IoE) in technology vertical of "Technologies for Internet of Things and Internet for Everything" established at IIT Bombay, and Technology and Innovation Foundation in technology vertical of "Technologies for Agriculture and Water" established at Indian Institute of Technology (IIT), Ropar.

Precision agriculture, predictive and forecasting models, and AI-based technologies for crop and soil health monitoring are being developed by the AI4ICPS Foundation. 1102 start-ups in the agricultural and related industries have been chosen thus far, and Rs. 66.83 crore has been disbursed in instalments. Before receiving funding, these start-ups received two months of training at different agribusiness incubation centres, such as KPs and R-ABIs.

OUTCOMES

The findings of this study highlight several potential outcomes of implementing AI and IoT technologies in Indian agriculture:

- *Increased Agricultural Productivity:* By optimizing resource use and mitigating risks, AI and IoT technologies can significantly increase crop yields, leading to higher agricultural output and improved food security.
- *Enhanced Farm Incomes:* Increased crop yields, reduced input costs, and improved market access through AI and IoT solutions can lead to higher farm incomes, improving the livelihoods of farmers.
- *Sustainable Agriculture:* Precision farming practices enabled by AI and IoT can help reduce the environmental impact of agriculture by minimizing resource use, reducing pollution, and promoting sustainable land management practices.
- *Improved Food Quality:* By enabling better monitoring and control of production processes, AI and IoT can contribute to improved food quality and safety.
- *Economic Growth:* The widespread adoption of AI and IoT in agriculture can drive economic growth by creating new jobs, fostering innovation, and boosting the agricultural sector's contribution to the national economy.
- *Social Development:* By empowering farmers with data-driven decision-making tools and improving their livelihoods, AI and IoT can contribute to social development and reduce rural poverty.

CONCLUSION

According to this report, the agriculture industry's success depends on the utilization of cutting-edge computer technology, particularly artificial intelligence (AI) and the Internet of Things (IoT). The continued existence of mankind is frequently considered to depend on agriculture. By integrating more modern IoT and AI technologies into current farming operations, it is possible to increase the productivity, quality, and quantity of crops produced in conventional farming. Primary research publications in the subject of agriculture were used in this study to analyse the present IoT and AI technologies. Furthermore, the most crucial elements of intelligent and sustainable agriculture were categorized. Crops, soil, weather, fertilizer, agricultural goods, pests, irrigation/water, machinery, fields, crops, and human resources are some of these factors. The main contribution this study makes is the AI or IoT technology framework for SSA. The exploration and development of an integrated AI and "IoT platform for SSA" has become more important as a direct result of this. The goal of this is to effectively address issues that have arisen as a direct result of farming production's fragmentary nature.

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