Artificial Intelligence and Machine Learning Applications in Modern Agriculture: A Review of Current Trends and Future Prospects

Arpit Gupta[1] , Mannat Saggar[2] , Komal Sharma [3]

[1,2]**Student, Dept. of Computer Applications, Sri Aurobindo College of Commerce and Management, Ludhiana, India**

[3]**Assistant Professor, Dept. of Computer Applications, Sri Aurobindo College of Commerce and Management, Ludhiana, India**
guptarpit5@gmail.com, Saggarsmannat@gmail.com , komalsharma00061@gmail.com

ABSTRACT

Agriculture is changing as a result of artificial intelligence (AI) and machine learning (ML), which increase productivity, decrease expenses, and improve efficiency. AI-powered solutions assist farmers with weather forecasting, crop monitoring, and farming process automation .Machine learning enables intelligent decision-making by evaluating vast volumes of agricultural data. This study examines the most recent uses of AI and ML in agriculture, such as yield prediction, crop monitoring, precision farming, and pest control. It also covers difficulties including exorbitant prices, a lack of technological expertise, and concerns about data protection. The study concludes by outlining the prospects for the future, with a focus on enhanced sustainability and automation powered by AI.

Keywords: Automation, precision farming, Agriculture, Machine Learning, Artificial Intelligence, Crop Monitoring

1. Introduction

With its historic roots, agriculture continues to be an important industry in India, employing around 60% of the workforce and making up roughly 18% of the country's GDP. However, its importance is called into question by dwindling contributions brought on by the expansion of other industries, the loss of farmland owing to urbanization, the unpredictability of climate change-induced weather, and antiquated farming methods. Given that the global population is predicted to reach 9.7 billion by 2050, with significant implications for India's food demand although, there is

tremendous pressure to boost agricultural production by 70% in order to guarantee food security [1]. This calls for improved planning, the use of cutting-edge methods, and the resolution of environmental issues. This paper provides a thorough investigation, systematically addressing each important aspect.

Figure 1: Precision Agriculture

1.1 Historical and Antiquated Methods of Agriculture

Around 2500 BCE, the Indus Valley Civilization marked the beginning of agriculture in India. Crop rotation and irrigation were two of the sophisticated agricultural practices that made this ancient civilization famous. Wheat, barley, and other legumes may have been grown, according to archeological findings. The domestication of animals, particularly cattle, also played a critical role in early agricultural methods [2].

1.2 Historical Developments in Agriculture

Indian agriculture has seen a number of innovations over the years. Texts such as the Arthashastra and the Brihat Samhita provide documentation of agricultural methods during the Mauryan and Gupta periods. During these times, a variety of fruits, rice, and sugarcane were introduced, diversifying agricultural production. New irrigation methods, such as digging wells and canals, became popular during the Middle Ages.

1.3 Research Gap and Motivation

While numerous studies have explored the use of artificial intelligence (AI) and machine learning (ML) in agriculture, there remains a noticeable lack of comparative evaluations across different AI techniques in terms of cost, scalability, environmental impact, and accessibility for farmers with varying resources. Moreover, current literature often focuses on isolated applications, neglecting the integration of AI solutions across the entire agricultural value chain—from soil preparation to post-harvest management. This paper aims to bridge

this gap by offering a comparative analysis and identifying directions for more inclusive, sustainable, and scalable AI-driven farming solutions.

2. Agriculture's Current Situation

a) Principal Crops and Areas

Numerous crops may be grown in India due to its varied climate and topography. Rice, wheat, and millets are among the basics that the nation produces in large quantities. The Deccan Plateau, which produces a large number of pulses and oilseeds, and the Indo-Gangetic Plains, which are noted for their wheat and rice, are important agricultural regions. The agricultural sector also benefits from cash crops including sugarcane, cotton, and jute.

b) Techniques and Procedures in Farming

In India, modern farming methods coexist with traditional farming methods. In many areas, crop rotation, mixed cropping, and the use of organic fertilizers are standard practices. Modern techniques like chemical fertilizers, high-yielding variety (HYV) seeds, and sophisticated irrigation techniques are being adopted more and more, though.

c) GDP and employment contributions

An important part of the Indian economy is still agriculture. About 60% of the workforce is employed by it, and it makes up about 18% of the GDP. However, as the nation diversifies its economic basis through the expansion of industry and services, the sector's contribution has been steadily decreasing.

d) Obstacles Indian Agriculture Faces

Unpredictable weather patterns are a result of the Earth's average temperature rising due to global warming. Consequently, crop yields have declined due to the increase in droughts and heavy rainfall. Due to their frequent lack of preparation, farmers suffer large financial losses.

e) Absence of Infrastructure and Modern Technology

One of the biggest problems facing Indian agriculture is the lack of water. In many areas, the overuse of groundwater for agriculture has caused water tables to drop. Conventional irrigation techniques frequently waste water due to their inefficiency. Water-efficient techniques like sprinkler and drip irrigation must be implemented immediately.

f) Absence of Infrastructure and Modern Technology

In India, many farmers continue to use antiquated farming methods and equipment. Productivity is hampered by limited access to contemporary technologies, such as precise farming instruments and mechanized machinery. Post-harvest losses are also caused by poor infrastructure, like transportation and storage systems.

3) AI IN THE SMART AGRI FIELD

1. Accurate farming: Using AI to collect and evaluate data from various sources, including satellites, drones, and ground sensors, is known as precision farming. Farmers may better grasp the unique requirements of their fields, down to the square meter, with the use of this data. After processing the data, AI systems offer insights on [2]:

AI is capable of analyzing soil samples to ascertain moisture content, pH balance, and nutrient levels. This aids farmers in determining when to irrigate their crops and what fertilizers to use.

Crop health: AI can identify plant stress brought on by pests, illnesses, or insufficient nutrients by examining photos taken by drones. This lessens the need for extensive pesticide application by enabling focused treatment.

Weather patterns: Farmers can arrange their planting and harvesting timetables with the aid of AI models that can accurately forecast weather variations. This maximizes productivity and reduces crop damage.

2. Weed Control Automation: In agriculture, weed control is a major problem that frequently calls for a large investment of time and money in chemicals. AI-driven automated weed management systems, like Farm Wise's Titan FT-35, identify and mechanically remove weeds using robots and computer vision. This method lowers labor expenses and lessens the need for herbicides.

Figure 2: Robotics in Agriculture

Benefits: Reduces the use of chemicals, which lessens contamination of the soil and water. Cost-effectiveness: Reduces costs related to purchasing herbicides and performing manual work.

3. Monitoring the Health of Livestock: AI is being used more and more to track the health of animals, guaranteeing early sickness identification and enhancing animal welfare in general.
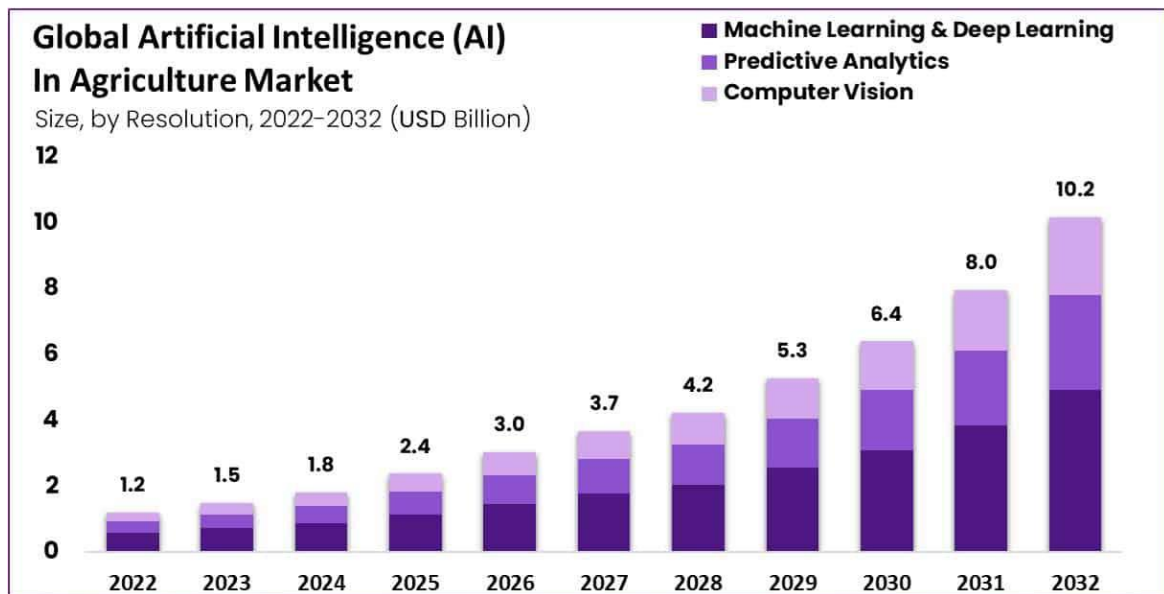
Figure 3: Global Artificial Intelligence (AI) in agriculture market

4. Crop Management Using Predictive Analytics: AI algorithms forecast crop yields by examining past data and present circumstances, which helps with resource allocation and planning. Farmers can plan planting and harvesting operations more efficiently thanks to AI's precise weather forecasts. AI analyzes market data to predict price and demand changes, assisting farmers in choosing crops and scheduling sales.

5. Intelligent Greenhouse Administration: Climate Control: AI systems modify light levels, humidity, and temperature to meet the needs of particular crops. Resource efficiency lowers operating costs by making the best use of energy and water resources. Disease Prevention: Keeps an eye on signs of plant health to stop disease outbreaks in controlled settings.

6. Monitoring of Soil Health: Sensor Integration: Real-time insights into soil conditions can be obtained by combining data from soil sensors with artificial intelligence systems. Data Analysis: AI uses data on soil composition to suggest suitable soil management techniques, like cover crops and crop rotation.

7. AI-Driven Advisory Services and Marketplaces: AI-powered chatbots, such as Darli, improve accessibility by providing farmers with multilingual advice on market prices, crop management, and best practices. AI systems connect farmers and consumers, streamlining supply chains and guaranteeing reasonable prices.

8. Self-governing Farming Machinery
Driverless Tractors: Outfitted with GPS and artificial intelligence, these tractors carry out precise operations like planting and plowing. By identifying and gathering ripe food, AI-powered robots boost productivity and lessen the need for human labor.

4. Literature Review

Over the decades, smart agriculture—also referred to as precision farming or digital agriculture—has developed by incorporating technology to improve farming sustainability and efficiency. There are various significant stages in the transition from conventional farming practices to contemporary, technologically advanced agriculture.

1. Traditional Farming (Prior to the 19th Century)

Agriculture was dependent on manual labor, crude tools, and the cycles of the weather prior to the Industrial Revolution [3]. To grow crops, farmers relied on trial-and-error techniques and information passed down through the generations. Important developments included crop rotation, irrigation methods, and animal domestication.

2. 19th- and early 20th-century mechanized agriculture

Farming was transformed by the development of devices like the tractor, mechanized plow, and seed drill. Steam and gasoline-powered machinery were developed during the Industrial Revolution, which decreased labor costs and increased productivity. Large-scale farming began as a result of improved fertilizers and pest control brought about by scientific breakthroughs [4].

3. The 1940s to 1970s Green Revolution

High-yield crops, artificial fertilizers, insecticides, and sophisticated irrigation methods were all brought about by the Green Revolution. The development of disease-resistant wheat by Norman Borlaug was essential to the expansion of food production. But this stage also raised worries about environmental harm, water use, and soil erosion [5].

4. Early Digital Agriculture (1980s – 1990s)

The introduction of computers, satellite imaging, and Geographic Information Systems (GIS) in agriculture laid the foundation for smart farming. Farmers started using precision farming techniques, such as soil mapping, weather forecasting, and remote sensing, to optimize crop yields and resource use.

5. Smart Agriculture's Ascent (2000s–Present)

Smart agriculture emerged as a result of the quick growth of digital farming technologies in the twenty-first century. Among the major innovations are**:**

Internet of Things (IoT): Field sensors track temperature, fertilizer levels, and soil moisture in real time.

Drones and Robotics: While robots aid in weeding and harvesting, drones help with crop monitoring, pesticide application, and field health analysis.

Artificial Intelligence (AI) and Machine Learning (ML): AI evaluates vast datasets to maximize agricultural management, irrigation, and pest control. Big Data & Cloud **Computing**: To make well-informed choices regarding planting, fertilization, and harvesting, farmers rely on data analytics and cloud-based systems.

Automated Equipment & GPS-guided Tractors: Automatic irrigation systems and self-driving tractors increase productivity and lower labor expenses [6].

Blockchain in Agriculture: Guarantees supply chain transparency, assisting farmers in receiving fair pricing and lowering food fraud

5. Current Applications of AI in Agriculture

AI is playing an increasingly significant role in agriculture, offering innovative solutions to improve efficiency and productivity. Some of the most common applications include [7]:

1. Precision Agriculture – AI helps collect and analyze data related to crops, soil, and weather conditions, enabling farmers to optimize their farming techniques. This includes better management of irrigation, fertilization, and pest control. AI-powered drones can monitor fields, identifying areas that require additional water or nutrients. Additionally, AI-driven models can predict crop yields by analyzing weather patterns and other variables, aiding farmers in making informed decisions about planting, harvesting, and selling their produce.

2. Agricultural Robotics – AI-driven robots are being used to automate various farming tasks, such as weeding, harvesting, and packaging. These robots help lower labor costs and improve operational efficiency. AI-powered robotic systems can selectively remove weeds without harming crops, reducing the reliance on herbicides. By utilizing advanced algorithms, these robots navigate fields, identify crops, and even apply pesticides in a targeted manner. Agricultural robots are addressing labor shortages while increasing productivity.

3. AI-Powered Drones – Drones equipped with AI-powered cameras assist in monitoring crop health, detecting diseases, and identifying pest infestations. This enables farmers to take swift action to prevent the spread of pests and diseases. By providing real-time aerial insights, AI-driven drones help in making timely and effective decisions for better crop management.

4. **Machine Learning in Agriculture** – Machine learning algorithms are used to forecast crop yields, predict weather patterns, and optimize irrigation schedules. These algorithms analyze various factors to determine the exact water requirements of crops, preventing over- or under-watering. AI-driven insights improve decision-making and streamline agricultural processes.

5. Big Data Analytics – AI processes vast amounts of agricultural data to identify trends and patterns. By analyzing data from weather stations, soil sensors, and drones, AI can pinpoint areas vulnerable to drought or flooding. This helps farmers take proactive measures

6. Comparative Analysis of AI Approaches in Agriculture

Artificial intelligence applications in agriculture are diverse, each offering unique advantages and facing specific limitations. A comparative analysis is essential to understand their effectiveness in different agricultural settings.

Table 1: Summary of the key comparisons.

AI Approach	Primary Use	Advantages	Limitations	Suitability
Precision Agriculture (AI+Sensors)	Soil, crop monitoring	Increased yields, resource optimization	High setup cost, technical complexity	Large & medium farms
Agricultural Robotics	Harvesting, weeding	Labor cost reduction, efficiency	Very expensive, maintenance issues	Large industrial farms
AI-Powered Drones	Crop health surveillance	Real-time data, wide coverage	Costly, regulatory barriers	Large farms
Predictive Analytics	Yield, market forecasting	Decision-making support	Data dependency, model inaccuracies	Small, medium & large farms
AI Chatbots and Marketplaces	Farmer advisories, market linkage	Accessibility, multilingual support	Limited personalization	Small & medium farmers

7. Future Trends in AI for Agriculture

AI in agriculture is still evolving, but its potential is immense. As AI technology advances, new and innovative applications are expected to emerge. Beyond current applications, the evolution of AI in agriculture points toward several emerging trends that are likely to shape the industry's future trajectory.

1. **AI for Developing Improved Crop Varieties** – AI can help identify genes linked to desirable traits in crops, enabling the creation of new varieties that are more resistant to pests and diseases, require less water, and yield higher harvests. AI-driven advancements could lead to crops that can withstand extreme weather conditions such as droughts or floods, reducing agricultural losses caused by climate change.

2. **AI-Enhanced Livestock Management** – AI can be utilized to track livestock movements, monitor their health, and optimize feeding and breeding programs, leading to better animal welfare and productivity. Early detection of diseases through AI-driven monitoring can help farmers take preventive measures before illnesses spread, improving overall livestock health.

3. **AI for Sustainable Farming Practices** – AI can assist farmers in minimizing their environmental impact by optimizing irrigation schedules, reducing pesticide usage, and improving waste management. These AI-driven solutions can contribute to more sustainable agricultural practices, helping to mitigate climate change and other environmental concerns.

4. AI-Powered Personalized Farming

Personalized farming leverages AI to tailor agricultural practices based on the unique conditions of each field or farm. Using inputs such as soil analysis, historical yield records, satellite imagery, and real-time weather data, AI systems provide customized recommendations for crop selection, irrigation planning, fertilizer application, and pest management. Startups such as **CropX**, **Plantix**, and **AgriWebb** are already offering mobile-based platforms that deliver individualized advice to farmers, often via simple smartphone interfaces. These solutions enhance productivity by minimizing waste and optimizing input use, while simultaneously reducing environmental impact.

However, challenges include the affordability of these platforms for smallholder farmers, concerns over data privacy, and the need for local language support to ensure widespread usability. Overcoming these barriers will be key to scaling personalized AI-driven farming practices globally.

8. Real Case Studies and Empirical Data

Case Studies:

CASE 1: A 2020 study by Iowa State University demonstrated that using AI-powered precision agriculture techniques resulted in a 12% increase in maize yields and a 15% reduction in fertilizer use compared to traditional methods [2].

CASE 2: Given Thai and Maharashtra, the state government's pilot project using AI-based drone monitoring across 300 acres of cotton farms resulted in early detection of pest attacks, reducing pesticide usage by 22% and improving crop health [4].

9. Conclusion

Artificial intelligence is driving the evolution of agriculture into a data-driven, efficient, and sustainable industry. AI-powered solutions are equipping farmers with the tools to make well-informed decisions, optimize resource allocation, and enhance productivity—ranging from precision farming to predictive analytics. While challenges remain, the benefits of AI in agriculture are undeniable. As technology continues to advance, ensuring its responsible implementation will be essential to fostering a more resilient and food-secure future. AI has the potential to revolutionize agriculture, making it more efficient, productive, and sustainable. In the years ahead, we can expect even more innovative applications of AI in the agricultural sector.

References

[1] Gupta, A., & Anitha, J. (2020). Artificial intelligence and deep learning in agriculture. Precision Agriculture, 21, 1113-1133. DOI: 10.1007/s11119-019-09667-0

[2] Jain, S., Shivhare, A., et al. (2021). Application of artificial intelligence in agriculture and horticulture. Materials Today: Proceedings, 44, 2851-2854. DOI: 10.1016/j.matpr.2021.01.652

[3] Kaur, R., Singh, S., & Singh, A. (2018). Machine learning applications for improving precision agriculture: A review. Computers and Electronics in Agriculture, 151, 201-220. DOI: 10.1016/j.compag.2018.05.026

[4] Mail, M.F.; Maja, J.M.; Marshall, M.; Cutulle, M.; Miller, G.; Barnes, E. Agricultural Harvesting Robot Concept Design and System Components: A Review. AgriEngineering 2023, 5, 777–800. https://doi.org/10.3390/ agriengineering5020048.

[5] Mahibha G, Balasubramanian P (2023) Impact of Artificial Intelligence in Agriculture with special reference to agriculture information research. 11(1), 287-296.

[6] Mary H, K. Kalaiarasi, A. Stanley Raj (2022) Coconut Tree (Cocos Nucifera) Products: A review of Global cultivation and its benefits, Journal of Sustainability and Environmental Management, 1(2),257 264.

[7] Poonia, R. C., Saha, S., et al. (2020). Artificial intelligence in agriculture: A comprehensive review. Computers and Electronics in Agriculture, 176, 105548. DOI: 10.1016/j.compag.2020.105548

[8] Usama, M., Wu, Q., & He, H. (2020). Artificial intelligence in agriculture: A survey. Computers and Electronics in Agriculture, 172, 105345. DOI: 10.1016/j.compag.2020.105345.