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AI IN AGRICULTURE: THE FUTURE OF FARMING

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ABSTRACT

With the global population expected to reach 10 billion by 2050, agriculture faces immense pressure to increase productivity sustainably. The sector's future depends on innovative practices that maximize yields on existing farmland, and artificial intelligence (AI) stands as a promising solution to alleviate food shortages and meet the growing demand. AI empowers agriculture by enabling data-driven approaches across key areas like soil and weed management, crop health monitoring, yield prediction, and autonomous machinery. Through machine learning, computer vision and IoT sensors, AI enhances the precision of agricultural practices, helping farmers make informed decisions, optimize resources, and increase efficiency. For instance, precision agriculture, powered by AI, allows for real-time analysis of soil conditions, moisture, and crop health, while AI algorithms detect diseases early and analyze pest patterns, offering targeted solutions that minimize crop loss. AI-driven yield prediction models assist farmers in planning accurate harvests and reducing waste, while autonomous machinery automates labor-intensive tasks such as planting, weeding, and harvesting, reducing dependency on manual labor. Despite its benefits, AI in agriculture faces barriers, including high costs, limited access for small-scale farmers and data quality issues. Overcoming these challenges will require collaboration among technology developers, policymakers and farming communities to ensure equitable AI adoption. As AI continues to evolve, trends like climate-resilient crops and AI-based decision support systems promise to make agriculture more sustainable and resilient to climate change, advancing global food security.

Key words : Agricultural Sustainability, Artificial Intelligence, Crop Monitoring, Precision Agriculture, Smart Farming, Yield Prediction.

Introduction

Agriculture has long been the backbone of human civilization, essential for food security, economic growth, and livelihoods across the globe. However, in recent decades, this sector has encountered numerous challenges that threaten its ability to sustain a growing global population. Rapid climate change, diminishing arable land, soil degradation, unpredictable weather patterns, and water scarcity are just a few of the environmental stressors impacting agricultural productivity (Gryshova, 2024). Simultaneously, the demand for agricultural products continues to rise as the world's population grows, putting further pressure on farmers to maximize yields, improve efficiency and adopt sustainable practices.

In response to these challenges, Artificial Intelligence (AI) has emerged as a powerful tool to reshape modern agriculture. By utilizing advanced data analysis, machine learning, and automation, AI offers innovative solutions that can transform traditional agricultural methods into more efficient, precise and environmentally friendly practices. AI can process large volumes of complex data from various sources, such as weather patterns, soil sensors and satellite imagery, to provide actionable insights for farmers (Hassan, 2023). Through AI-powered tools, farmers can make data-driven decisions that optimize crop yields, reduce waste, and manage resources more effectively.

One of the most promising applications of AI in agriculture is precision farming, which allows for the precise management of crops and soil. AI-driven technologies, such as drone imaging and IoT sensors, enable real-time monitoring of crop health, soil conditions, and pest levels. This information allows farmers to apply inputs like water, fertilizers, and pesticides exactly where and when they are needed, reducing costs and minimizing environmental impact. Additionally, AI enhances crop health monitoring and early disease detection through computer vision, allowing for early interventions that can prevent widespread crop loss (Hoque and Padhiary, 2024).

As this paper explores, the integration of AI in agriculture not only offers technical advancements but also contributes to achieving sustainability goals by promoting efficient resource use and reducing environmental impact. With the continuous advancements in AI, the agricultural sector stands at the brink of a transformation, one that has the potential to foster a resilient, productive, and sustainable future for global agriculture.

Applications of AI in Agriculture

The use of AI in agriculture spans a wide array of applications that support farmers in optimizing crop yields, reducing waste and making more sustainable use of resources. This section explores some of the most impactful AI applications that are driving the transformation in modern agriculture.

Precision Agriculture

Precision agriculture uses AI to analyze real-time data from soil, weather conditions and crop health, enabling farmers to make precise decisions about resource application. Through sensors and IoT devices embedded in fields, AI systems monitor moisture levels, soil pH, nutrient content and even plant growth (Indira *et al.*, 2023). This allows farmers to apply water, fertilizers, and pesticides only when and where they are needed, reducing costs and minimizing the environmental impact. By employing predictive models based on historical data and current field conditions, AI-powered precision agriculture helps farmers maximize yields while conserving resources.

Crop Monitoring and Health Assessment

Crop monitoring involves the use of AI algorithms, particularly those powered by computer vision, to assess crop health on a large scale. Through drone or satellite imagery, AI systems can detect early signs of stress in plants, such as diseases, pest infestations and nutrient deficiencies. Machine learning models can analyze these images to identify patterns and determine appropriate interventions, often before symptoms are visible to the human eye. This proactive approach not only minimizes crop loss but also reduces reliance on chemical treatments, as targeted interventions can be applied (Bendig *et al.*, 2014).

Yield Prediction

Yield prediction models are essential for effective farm planning and resource allocation. By analysing data from previous seasons, current weather patterns, soil conditions, and crop health, machine learning algorithms can provide accurate yield predictions. This enables farmers to anticipate production levels and plan for market demand, labour, and logistics accordingly. AI-based yield prediction is particularly valuable in helping farmers adapt to climate variability, as these models can incorporate real-time data to adjust forecasts based on changing conditions (Chlingaryan *et al.*, 2018).

Automated Machinery

Automation has introduced efficiency and precision to labour-intensive agricultural tasks. AI-driven machinery, such as autonomous tractors, drones and robotic harvesters, can perform planting, weeding and harvesting tasks with minimal human intervention. Autonomous systems use machine learning to navigate fields, identify crops and manage tasks independently. This technology not only reduces the need for labour but also improves the consistency of field operations, leading to higher-quality yields and streamlined processes (Kaswan *et al.*, 2023).

Supply Chain Optimization

Beyond the field, AI plays a critical role in optimizing the agricultural supply chain. Machine learning models help predict demand trends, optimize inventory, and manage logistics to ensure that products reach the market

Fig. 1 : Application of AI in agriculture (Sinha *et al.*, 2023).

at peak freshness. With AI-driven demand forecasting and inventory planning, farmers and suppliers can reduce food waste and improve profitability. Moreover, AI enhances traceability by monitoring produce from farm to table, ensuring food quality and enabling quick response to supply chain disruptions.

Technologies Driving AI in Agriculture

Machine Learning in Agriculture: Data-Driven Analysis for Improved Productivity

Detail the role of data-driven models in analyzing agricultural data. Machine learning and deep learning are essential technologies in AI for agriculture, providing advanced, data-driven models that help analyze vast amounts of agricultural data for better decision-making and optimized practices. Here's a brief overview of their roles (Musanase *et al.*, 2023):

Data Analysis for Precision Agriculture: Machine learning (ML) algorithms analyze data from soil sensors, climate models and satellite imagery to create predictive models for crop yield, soil health, and pest outbreaks. This supports precision agriculture by allowing farmers to apply resources like water, fertilizers, and pesticides only where needed, reducing waste and improving crop productivity (Liakos *et al.*, 2018).

Deep Learning for Image Recognition: Deep learning, a subset of ML, excels in analyzing images, which is valuable for tasks like crop and weed identification, disease detection, and yield estimation. Using drones and cameras, deep learning models can classify plants and detect issues early, enabling timely interventions (Kamilaris and Boldu, 2018).

Predictive Maintenance and Robotics: ML models analyze operational data from farm machinery to predict maintenance needs, reducing equipment downtime. Robotics powered by AI can perform tasks like planting, harvesting, and weed control autonomously, making agriculture more efficient.

Climate and Market Predictions: Machine learning models analyze historical weather data and market trends to help farmers anticipate changes in climate or commodity prices, allowing them to make informed planting and selling decisions.

In Fig. 2 realistic depiction of a modern farm using AI-driven agricultural technologies, featuring drones, autonomous tractors, soil sensors and a farmer managing data on a tablet. This image captures the efficiency and sustainability brought by AI in agriculture.

Computer Vision in Agriculture: Disease Detection, Field Monitoring, and Harvest Automation

Fig. 2 : AI-Powered Precision Agriculture: A Realistic view of Modern Farming Technologies.

Computer vision is a critical AI technology in agriculture, enabling automated analysis of visual data collected from cameras, drones, and satellites. Here's how it is used in key areas (Tian *et al.*, 2023):

Identifying plant diseases : Computer vision algorithms can detect signs of plant diseases by analyzing images of crops in real time. Using pattern recognition, these systems identify symptoms like discoloration, leaf spots, or unusual growths, often before the disease spreads. Early detection allows farmers to apply targeted treatments, which can save entire fields and reduce the need for extensive pesticide use (Jones *et al.*, 2017).

Monitoring field conditions: By analyzing aerial images from drones and satellites, computer vision can assess field health metrics such as soil moisture, crop growth stages and nutrient deficiencies. These insights allow for precise resource management, as farmers can adjust irrigation, fertilization, or pest control based on real-time field conditions. This helps optimize yield while conserving resources and maintaining soil health (Wolfert *et al.*, 2017).

Automating harvesting : Computer vision is integral to robotic harvesters, which use visual data to recognize, locate, and pick ripe crops without damaging the plants. In fruit and vegetable harvesting, for example, computer vision systems enable robots to differentiate between ripe and unripe produce, allowing for efficient, labour-saving harvesting processes. This automation helps address labour shortages and reduces crop loss due to delays (Shamshiri *et al.*, 2018).

Fig. 3 illustrating the use of computer vision technology in agriculture, featuring drones for monitoring crop health, an autonomous robotic harvester picking ripe produce, and farmers using tablets to access real-time data. This scene captures the impact of AI-driven computer vision in improving agricultural efficiency and productivity.

Fig. 3 : Advanced computer vision in agriculture: drones, robotics and crop monitoring.

Overall, computer vision drives smarter, more efficient farming by enhancing disease management, monitoring, and automation, making agriculture more sustainable and productive.

IoT and Sensors: Real-Time Data on Soil, Weather, and Crop Health for AI Support IoT (Internet of Things) devices and sensors have revolutionized agriculture by enabling real-time monitoring of soil, weather, and crop health. These devices are typically deployed across farms to capture a wide range of environmental and agricultural data (Sundmaeker *et al*., 2022). Here's a deeper look at how these devices function and support AI-driven solutions:

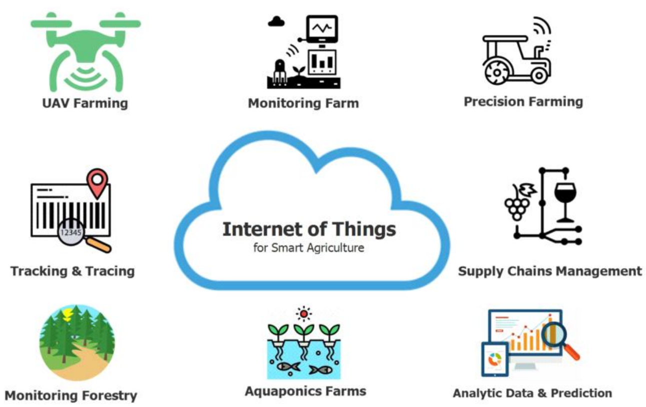

Fig. 4 : IoT application in the field of agriculture for smart farming (Farooq *et al*., 2019).

Soil sensors : These sensors are embedded in the ground and measure crucial factors like soil moisture, temperature, pH and nutrient levels. For example, moisture sensors help determine when to irrigate crops, preventing both overwatering and under watering. Nutrient sensors track the availability of key elements like nitrogen, phosphorus and potassium, allowing for precision fertilization (Silva *et al*., 2024).

Weather sensors : Weather stations placed in the field monitor atmospheric conditions such as temperature, humidity, rainfall, wind speed and solar radiation. By continuously collecting this data, they help farmers understand the current and future climate conditions, enabling them to make informed decisions on irrigation scheduling, pest control and overall farm management.

Crop health sensors : These sensors, often mounted on drones, satellites, or ground-based robots, assess crop health by measuring factors like chlorophyll content, leaf temperature, and colour changes. Technologies like multispectral and hyper spectral imaging allow for the detection of plant stressors such as drought, disease or pest infestations before they become visible to the naked eye.

Data integration and AI algorithms: The real-time data collected from these sensors is sent to a central cloud platform or local processing unit. AI algorithms process and analyze this vast amount of data to generate actionable insights. For example, AI can predict potential crop diseases by detecting patterns in environmental conditions and crop health indicators. It can also optimize irrigation schedules by correlating soil moisture levels with weather forecasts, ensuring crops receive the right amount of water at the right time.

Actionable insights and automation: AI can integrate data from various sensors to create personalized recommendations for farmers. For instance, if soil nutrients are low, the AI might suggest targeted fertilization in specific areas of the field. Additionally, automated systems like drones or robots can be used to take action based on AI analysis, such as applying pesticides, delivering fertilizers or adjusting irrigation systems.

Combining the capabilities of IoT sensors with AI, farmers can increase crop yields, reduce resource wastage and enhance sustainability. The ability to monitor crops in real-time, coupled with AI's predictive capabilities and provides a powerful tool for managing complex agricultural systems. This technology not only boosts productivity but also helps mitigate the environmental impact of farming.

Drones and robotics: AI-driven monitoring, pest control and fertilizer application

Drones and robotics are transforming agriculture by working alongside AI to perform a variety of tasks with high precision, enhancing efficiency, and reducing resource waste. Here's a closer look at how these technologies function (Hoque and Padhiary, 2024):

Monitoring and Crop Surveillance : Drones and robotics are revolutionizing crop monitoring and surveillance by providing farmers with advanced tools for real-time data collection. Drones, equipped with high-resolution cameras and multispectral or thermal sensors,

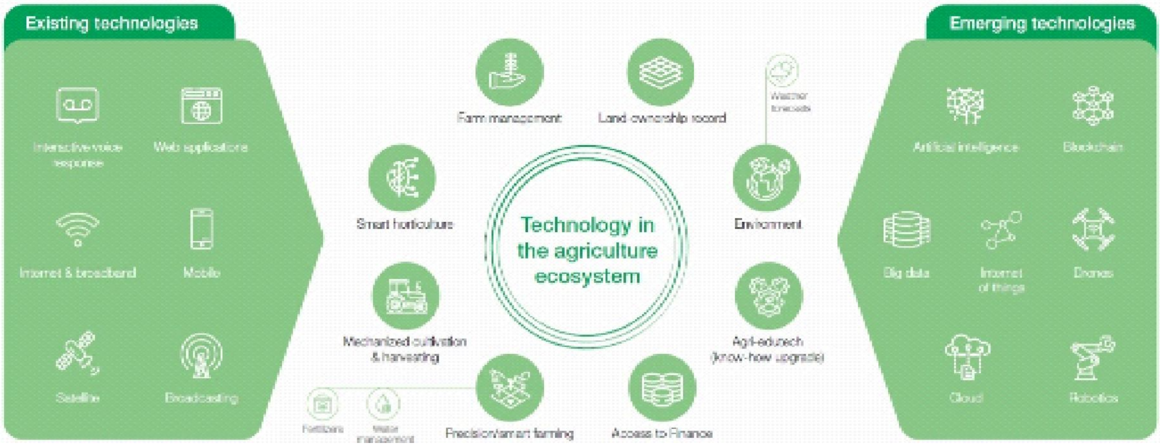

Fig. 5 : Existing technologies Vs emerging technologies in agriculture ecosystem (Singh *et al*., 2021).

can cover vast farm areas, capturing detailed images and data about crop health, soil conditions and growth stages. This data is processed by AI algorithms, which can detect early signs of plant stress, disease, or pest infestations, enabling farmers to take proactive measures before issues become widespread. On the ground, robotics, such as autonomous tractors or field scanners, offer close-up monitoring capabilities (Carvajal *et al*., 2019). These robots gather data on soil quality, plant height, and leaf colour, which is then analysed by AI systems to evaluate crop performance. Together, drones and robotics provide comprehensive insights that help farmers optimize crop management and improve overall yield.

Pest and Disease Detection and Spraying : Drones and robotics are transforming pest and disease management in agriculture through precision targeting and AI-driven automation. Drones, equipped with specialized sprayers, can precisely target areas of the field where pest infestations or diseases have been detected. Using AI-powered image recognition, the drones analyze captured visuals in real-time to identify affected regions, applying pesticides or fungicides only where needed. This targeted approach minimizes chemical use, preventing unnecessary spraying on healthy crops and reducing environmental impact. Similarly, autonomous robots, such as insecticide-spraying robots and robotic weeders, patrol fields to apply treatments directly to problem areas. These robots use AI to distinguish between crops, weeds and pests, ensuring that pesticides or herbicides are applied only where necessary, leading to more efficient and sustainable pest control. Together, drones and robotics enhance the accuracy and effectiveness of pest and disease management, improving crop health while reducing the reliance on chemicals (Storey *et al*., 2022).

Precise Application of Fertilizers : Drones and robotics are enhancing the precision and efficiency of fertilizer application in agriculture. Drones equipped with specialized tanks or granule dispensers can optimize fertilizer use by analyzing data from sensors and AI algorithms. The drones determine the exact amount of fertilizer required for specific areas of the field, applying it only where necessary. This targeted approach reduces waste, lowers costs, and minimizes environmental impact by preventing over-fertilization. Similarly, autonomous tractors and robotic applicators equipped with AI can adjust the fertilizer distribution based on real-time soil health data gathered from sensors in the field (Ziemba and Wątróbski, 2024). These machines determine the best locations and timing for fertilizer application, boosting crop yield while conserving valuable resources. Both technologies contribute to more sustainable farming practices, improving efficiency and reducing the environmental footprint of fertilizer use.

AI Integration

AI plays a central role in making drones and robots intelligent and autonomous. The AI system analyzes the data collected by these tools to identify patterns, predict crop health, and make decisions in real-time. For example, AI can help drones navigate complex terrains, avoid obstacles, and target areas with high accuracy. In addition, machine learning algorithms continuously improve their ability to detect anomalies, such as pest outbreaks or nutrient deficiencies, over time (Roh *et al*., 2019).

Benefits

Increased efficiency : Drones and robotics automate labour-intensive tasks like monitoring, spraying, and fertilizing, significantly reducing the need for manual labour and increasing operational efficiency.

Precision : These technologies ensure that inputs such as water, fertilizers, and pesticides are applied in the right amounts, improving crop health and minimizing environmental impact.

Sustainability : By optimizing resource usage and reducing waste, drones and robotics contribute to more sustainable farming practices. Precision application not only saves on costs but also protects ecosystems from overuse of chemicals.

Drones and robotics, in conjunction with AI, are revolutionizing agriculture by enhancing the accuracy of monitoring, pest control, and fertilization. These tools provide farmers with powerful capabilities to improve crop yields, reduce waste, and adopt more sustainable farming practices.

Challenges and Limitations

Data Scarcity and Quality in Agriculture

A major challenge in AI adoption for agriculture is data scarcity and quality. AI models require large amounts of high-quality data, such as soil conditions, weather patterns and crop health, to make accurate decisions. However, many farmers lack reliable data due to limited sensor coverage, poor data collection, or inconsistent recording, especially in remote areas. Additionally, inaccurate or incomplete data can lead to flawed predictions, such as miscalculating irrigation needs or pest risks, impacting crop yield (Kebede *et al*., 2024). To improve AI effectiveness, robust data collection, sensor calibration, and better data-sharing infrastructure are crucial for accurate and reliable results.

High Costs in Agriculture

The high costs of AI tools and technologies are a significant barrier for small farmers in agriculture. Advanced technologies like drones, IoT sensors, and autonomous machinery require substantial investment, making them unaffordable for farmers with limited resources. These upfront costs can prevent small farmers from adopting innovations that could improve efficiency and crop yields, creating a divide between large and small farms ((Hasteer *et al*., 2024)). To overcome this, affordable and scalable AI solutions are needed. Government subsidies, financing options, and low-cost open-source tools could help small farmers access these technologies, improving productivity and sustainability while making smart farming more inclusive.

Technical Expertise in Agriculture

A key barrier to AI adoption in agriculture is the lack of technical expertise, particularly among small and medium-scale farmers in rural areas. AI systems, drones, robotics and IoT sensors require specialized knowledge for operation and maintenance, which many farmers lack (Basso and Antle, 2020). Training is essential to help them operate these technologies, use sensors for real-time data collection, and interpret AI recommendations for tasks like irrigation and pest control. Given the rapid advancement of AI, continuous skill updates are needed, but access to training resources is limited in rural areas. Governments, agricultural organizations and tech providers must collaborate to offer affordable, accessible training programs through online courses, mobile tools and local workshops to empower farmers and optimize AI use in farming.

Ethical Concerns in Agriculture

Fig. 6 : Challenges of AI in agriculture sector (Hasteer *et al*., 2024).

In agriculture, the increasing use of AI technologies raises several ethical concerns. Data privacy is a key issue, as AI tools collect vast amounts of sensitive data about farm operations, soil and crops. Ensuring secure and responsible use of this data is vital to protect farmers' rights. Another concern is the environmental impact of AI, as the production, maintenance, and disposal of technology, like drones and sensors, contribute to energy consumption and carbon emissions. Sustainable practices and renewable energy use are essential to mitigate these effects. Lastly, over-reliance on AI could reduce farmers' independence and decision-making ability, especially if AI systems malfunction or overlook factors like unpredictable weather or pests. Balancing AI adoption with ethical considerations is crucial for sustainable and responsible farming.

Future Prospects

The future of AI in agriculture holds exciting potential for advancing sustainability, resilience, and productivity on a global scale. As technology continues to evolve, AI-driven solutions are likely to become even more sophisticated, accessible, and integrated into agricultural systems. This section explores emerging trends and future applications of AI in agriculture that promise to address longstanding challenges and adapt to new ones.

Emerging Trends

Climate-Resilient Crops

Climate change is a pressing challenge for agriculture, with unpredictable weather patterns affecting crop yields and farm management. AI models are now being developed to support the creation of climate-resilient crops. By analyzing data on crop genetics, weather patterns and soil health, AI can help scientists breed crops that are more tolerant to extreme temperatures, drought, and pests (Javaid *et al*., 2023). These advancements could enable farmers to grow crops in regions previously unsuitable for agriculture, ensuring food security as climates shift.

Personalized Farming

AI-powered systems are evolving to provide personalized farming recommendations tailored to the unique conditions of each field or crop. With the combination of big data and AI, farms can receive specific guidance on planting times, crop rotations, irrigation schedules and pest control methods based on their individual circumstances. Personalized farming could transform small-scale farming, enabling farmers to maximize their productivity by following data-driven practices that cater to their specific soil, climate and crop requirements.

AI-Driven Decision Support Systems

Decision support systems (DSS) that incorporate AI are expected to become central to farm management. By gathering and processing vast amounts of real-time data, these systems provide actionable insights to farmers, from planting and harvesting times to fertilizer application and pest control. AI-driven DSS can also provide simulations to help farmers predict the impact of different farming strategies and scenarios, enabling them to make well-informed decisions that reduce risks and improve profitability (Ruiz-Real *et al*., 2020).

Policy and Support Needs

Government Support and Policy Initiatives

For AI technologies to be widely adopted in agriculture, there must be strong support from governments in the form of funding, subsidies and favourable policies. Governments can facilitate the adoption of AI by creating educational programs, providing financial aid to small and mid-sized farmers and supporting research initiatives. Policy initiatives should focus on addressing the digital divide, ensuring that even small-scale farmers have access to the necessary technology, internet, and AI training to benefit from these advancements (Ayed and Hanana, 2021).

Collaborative Innovation and Public-Private Partnerships

The future of AI in agriculture depends on the collaboration between agricultural technology companies, research institutions and farmers. Public-private partnerships can accelerate the development and distribution of AI solutions, making them more affordable and accessible. Through these collaborations, innovative AI tools and systems can be deployed and fine-tuned to meet the real-world needs of farmers in various regions. By involving farmers directly in the innovation process, AI technologies can become more relevant, scalable and sustainable.

Ethics and Sustainability Considerations

As AI becomes more embedded in agriculture, ethical and environmental considerations will be increasingly important. Sustainable AI development will involve careful attention to the environmental impact of technology manufacturing, data storage, and energy use. Additionally, ethical considerations must be taken into account, such as ensuring data privacy for farmers and protecting biodiversity by promoting eco-friendly farming practices (Sánchez *et al*., 2020).

Conclusion

The integration of Artificial Intelligence into agriculture marks a significant shift toward a future of efficient, sustainable and resilient food production. As this paper has explored, AI offers numerous applications that enhance the precision, productivity, and profitability of farming. Through innovations in precision agriculture, crop health monitoring, yield prediction, and automated machinery, AI addresses some of the most pressing challenges facing agriculture today, from resource scarcity to climate unpredictability. These advancements are essential not only for increasing food production but also for promoting environmentally friendly practices that conserve resources and reduce waste. Looking ahead, AI-driven agriculture holds promise in emerging areas such as climate-resilient crops, personalized farming, and advanced decision support systems, each of which will be instrumental in adapting to the rapidly changing climate and evolving market demands. However, realizing the full potential of AI in agriculture requires addressing certain challenges. Barriers such as high costs, data accessibility, and limited technical expertise can limit adoption, particularly among small-scale farmers. To bridge these gaps, collaboration between governments, technology companies and agricultural communities is essential. Policies that support funding, digital literacy, and access to technology are crucial to making AI tools accessible and beneficial to all farmers. As AI continues to develop, ethical and sustainability considerations must also be prioritized. A careful approach to AI implementation can ensure that technological advances align with the goals of biodiversity conservation, data privacy and social responsibility. In conclusion, the role of AI in agriculture is transformative, offering innovative solutions to help meet the demands of global food security while advancing sustainability. By fostering continued research, policy support, and collaborative efforts, AI has the potential to revolutionize agriculture, making it resilient, adaptive, and capable of supporting future generations.

References

Basso, B. and Antle J. (2020). Digital agriculture to design sustainable agricultural systems. *Nature Sustainability*, **3(4)**, 254-256.

Ben Ayed, R. and Hanana M. (2021). Artificial intelligence to improve the food and agriculture sector. *J. Food Qual.*, **2021(1)**.

Bendig, J., Bolten A., Bennertz S., Broscheit J., Eichfuss S. and Bareth G. (2014). Estimating biomass of barley using crop surface models (CSMs) derived from UAV-based RGB imaging. *Remote Sensing*, **6(11)**, 10395-10412.

Carvajal-Yepes, M., Cardwell K., Nelson A., Garrett K.A., Giovani B., Saunders D.G., Kamoun S., Legg J.P., Verdier V., Lessel J. and Neher R.A. (2019). A global surveillance system for crop diseases. *Science*, **364(6447)**, 1237-1239.

Chlingaryan, A., Sukkarieh S. and Whelan B. (2018). Machine learning approaches for crop yield prediction and nitrogen status estimation in precision agriculture: A review. *Comput. Elect. Agricult.*, **151**, 61-69.

Farooq, M.S., Riaz S., Abid A., Abid K. and Naeem M.A. (2019). A Survey on the Role of IoT in Agriculture for the Implementation of Smart Farming. *Ieee Access*, **7**, 156237-156271.

Gryshova, I., Balian A., Antonik I., Miniailo V., Nehodenko V. and Nyzhnychenko Y. (2024). Artificial intelligence in climate smart in agricultural: toward a sustainable farming future. *Access to science, business, innovation in the digital economy*, **5(1)**, 125-140.

Hassan, M., Kowalska A. and Ashraf H. (2023). Advances in deep learning algorithms for agricultural monitoring and management. *Appl. Res. Artific. Intellig. Cloud Computing*, **6(1)**, 68-88.

Hasteer, N., Mallik A., Nigam D., Sindhwani R. and Van Belle J.P. (2024). Analysis of challenges to implement artificial intelligence technologies in agriculture sector. *Int. J. Syst. Assur. Engg. Manage.*, **15(5)**, 1841-1860.

Hoque, A. and Padhiary M. (2024). Automation and AI in Precision Agriculture: Innovations for Enhanced Crop Management and Sustainability. *Asian J. Res. Comput. Sci.*, **17(10)**, 95-109.

Indira, P., Arafat I.S., Karthikeyan R., Selvarajan S. and Balachandran P.K. (2023). Fabrication and investigation of agricultural monitoring system with IoT and AI. SN *Applied Sciences*, **5(12)**, 322.

Javaid, M., Haleem A., Khan I.H. and Suman R. (2023). Understanding the potential applications of Artificial Intelligence in Agriculture Sector. *Advanced Agrochem*, **2(1)**, 15-30.

Jones, J.W., Antle J.M., Basso B., Boote K.J., Conant R.T., Foster I. and Wheeler T.R. (2017). Toward a new generation of agricultural system data, models, and knowledge products: State of agricultural systems science. *Agricult. Syst.*, **155**, 269-288.

Kamilaris, A. and Prenafeta-Boldú F.X. (2018). Deep learning in agriculture: A survey. *Comput. Elect. Agricult.*, **147**, 70-90.

Kaswan, K.S., Dhatterwal J.S., Baliyan A. and Jain V. (2022). Special sensors for autonomous navigation systems in crops investigation system. In : *Virtual and Augmented Reality for Automobile Industry: Innovation Vision and Applications* (pp. 65-86). Cham: Springer International Publishing.

Kebede, E.A., Abou Ali H., Clavelle T., Froehlich H.E., Gephart J.A., Hartman S. and Davis K.F. (2024). Assessing and addressing the global state of food production data scarcity. *Nat. Rev. Earth Environ.*, **5(4)**, 295-311.

Liakos, K.G., Busato P., Moshou D., Pearson S. and Bochtis D. (2018). Machine learning in agriculture: A review. *Sensors*, **18(8)**, 2674.

Musanase, C., Vodacek A., Hanyurwimfura D., Uwitonze A. and Kabandana I. (2023). Data-driven analysis and machine learning-based crop and fertilizer recommendation system for revolutionizing farming practices. *Agriculture*, **13(11)**, 2141.

R. Shamshiri, R., Weltzien C., Hameed I.A., J Yule I., E Grift T., Balasundram S.K. and Chowdhary G. (2018). Research and development in agricultural robotics: A perspective of digital farming.

Roh, Y., Heo G. and Whang S.E. (2019). A survey on data collection for machine learning: a big data-ai integration perspective. *IEEE Trans. Knowl. Data Engg.*, **33(4)**, 1328-1347.

Ruiz-Real, J.L., Uribe-Toril J., Torres Arriaza J.A. and de Pablo Valenciano J. (2020). A look at the past, present and future research trends of artificial intelligence in agriculture. *Agronomy*, **10(11)**, 1839.

Sánchez, J.M., Rodríguez J.P. and Espitia H.E. (2020). Review of artificial intelligence applied in decision-making processes in agricultural public policy. *Processes*, **8(11)**, 1374.

Silva, F.M., Queirós C., Pereira M., Pinho T., Barroso T., Magalhães S., Boaventura J., Santos F., Cunha M. and Martins R.C. (2024). Precision Fertilization: A critical review analysis on sensing technologies for nitrogen, phosphorous and potassium quantification. *Comput. Elect. Agricult.*, **224**, 109220.

Singh, R.K., Berkvens R. and Weyn M. (2021). AgriFusion: An architecture for IoT and emerging technologies based on a precision agriculture survey. *IEEE Access*, **9**, 136253-136283.

Sinha, N.K., Kumar J., Kumar D., Mishra R., Thakur J.K., Shinogi K.C., Somasundaram J. and Mohanty M. (2023). Application of Artifical Intelligence (AI) in Agriculture An Indian Perspective. *Harit Dhara*, **5(2)**, 9-11.

Storey, G., Meng Q. and Li B. (2022). Leaf disease segmentation and detection in apple orchards for precise smart spraying in sustainable agriculture. *Sustainability*, **14(3)**, 1458.

Sundmaeker, H., Verdouw C., Wolfert S. and Freire L.P. (2022). Internet of food and farm 2020. In : *Digitising the industry internet of things connecting the physical, digital and virtualworlds* (pp. 129-151). River Publishers.

Tian, H., Wang T., Liu Y., Qiao X. and Li Y. (2020). Computer vision technology in agricultural automation—A review. *Informat. Process. Agricult.*, **7(1)**, 1-19.

Wolfert, S., Ge L., Verdouw C. and Bogaardt M.J. (2017). Big data in smart farming–a review. *Agricult. Syst.*, **153**, 69-80.

Ziemba, E. and Wątróbski J. (Eds.) (2024). *Adoption of Emerging Information and Communication Technology for Sustainability*. CRC Press.