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A Comprehensive Review on Exploring the Synergies between AI and Agriculture Practices within the Sector

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ABSTRACT
Artificial Intelligence (AI) technology has ushered in sweeping changes to traditional farming practices, offering innovative solutions to long-standing challenges. This comprehensive study highlights the far-reaching impact of AI in agriculture, providing a detailed examination of its diverse applications across sectors. From optimizing resource allocation to increasing production efficiency and reducing environmental concerns, AI is manifested through autonomous machinery, predictive analytics, precision farming and advanced crop monitoring systems. Furthermore, by rapidly analyzing huge datasets encompassing weather patterns, soil conditions and crop health indicators, AI-powered technologies accelerate decision-making processes. Supported by empirical evidence and a thorough review of existing literature, this study clearly demonstrates the tangible benefits of AI integration in agriculture. These benefits include substantial cost savings, increased yields, and promotion of sustainable land management practices, thereby promoting global food security. However, the ethical deployment of AI in agriculture requires careful consideration of various barriers, including data security, accessibility, and compliance with legal frameworks. Towards adapting agriculture to emerging demands while promoting greater efficiency, resilience and sustainability, stakeholders are urged to adopt AI through fostering multidisciplinary collaboration and facilitating information exchange. By doing so, the agriculture industry can harness the full potential of AI, ensuring its alignment with societal needs and ethical imperatives.
Keywords: *AI, sustainable land management, sustainability, soil conditions, and crop health indicators.*

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INTRODUCTION

Agriculture is one of the oldest and most essential human activities, providing food, feed, fiber, and fuel for billions of people around the world [1]. However, agriculture also faces many challenges in the 21st century, such as population growth, climate change, land degradation, water scarcity, food insecurity, and environmental pollution [2, 3]. To address these challenges, there is a need for innovative solutions that can enhance agricultural productivity, efficiency, sustainability, and resilience [4, 5].

Artificial intelligence (AI) is a branch of computer science that aims to create machines or systems that can perform tasks that normally require human intelligence, such as perception, reasoning, learning, decision-making, and problem-solving [6]. AI has been advancing rapidly in recent years, thanks to the availability of large amounts of data, powerful computing resources, and novel algorithms [7]. AI has already demonstrated remarkable achievements in various domains, such as natural language processing, computer vision, speech recognition, machine translation, and game playing [8].

AI has also been increasingly applied to agriculture, offering new opportunities for improving various aspects of agricultural production and management [9]. AI can help farmers and agronomists monitor crop growth, detect pests and diseases, predict yield, optimize irrigation and fertilization, implement precision farming, and manage the supply chain [10]. AI can also help researchers and policymakers analyze agricultural data, model crop systems, simulate scenarios, and design interventions [11]. AI can thus contribute to the achievement of the Sustainable Development Goals (SDGs) related to agriculture, such as ending hunger, ensuring food security, promoting sustainable agriculture, and combating climate change [1].

However, AI also poses some challenges and risks for agriculture, such as data quality, privacy, security, bias, fairness, accountability, transparency, explainability, and human-machine interaction [12, 13]. AI

also raises some ethical, social, and environmental questions, such as the impact of AI on labor, livelihood, culture, biodiversity, and human dignity [14, 15]. Therefore, there is a need for a holistic and interdisciplinary approach to assess the benefits and costs of AI adoption in agriculture, and to ensure that AI is aligned with the values and interests of the stakeholders involved [16].

This research paper, comprehensively review the current state, challenges, and opportunities of applying AI techniques to various aspects of agricultural production and management.

We organize the research paper into the following sections:

- **Section A: Crop Monitoring.** We review the methods and applications of using AI to monitor crop growth, health, and quality using various sources of data, such as satellite imagery, drones, sensors, and smartphones [17, 18].
- **Section B: Pest and Disease Detection.** We review the methods and applications of using AI to detect and identify pests and diseases affecting crops and to provide diagnosis and treatment recommendations [19, 20].
- **Section C: Yield Prediction.** We review the methods and applications of using AI to predict crop yield at various scales and time horizons and to provide yield gap analysis and risk res
- **Section D**: Irrigation and Fertilization Optimization. We review the methods and applications of using AI to optimize irrigation and fertilization schedules and amounts and to provide water and nutrient management advice [21, 22].
- **Section E:** Precision Farming. We review the methods and applications of using AI to implement precision farming, which involves the use of site-specific and variable-rate technologies to optimize crop inputs and outputs [17, 23].
- **Section F:** Supply Chain Management. We review the methods and applications of using AI to manage the supply chain of agricultural products, from farm to fork, and to provide traceability, quality control, and market intelligence [24].
- **Section G:** Ethical, Social, and Environmental Implications. We discuss the ethical, social, and environmental implications of AI adoption in agriculture, and provide some recommendations for ensuring responsible and inclusive AI development and deployment.
- **Conclusion and Future Directions.** We conclude the article by summarizing the main findings and highlighting some future directions and challenges for AI research and development in agriculture [25].

In addition to its traditional roles, modern agriculture is also tasked with meeting the evolving demands of a growing global population and addressing pressing environmental concerns [3]. These challenges necessitate innovative approaches to enhance productivity while minimizing adverse impacts on the environment and ensuring food security for future generations [5].

Amidst these challenges, Artificial Intelligence (AI) has emerged as a promising technology with the potential to revolutionize agriculture by enabling more efficient and sustainable practices [9]. The application of AI in agriculture holds promise for addressing critical issues such as crop monitoring, pest detection, yield prediction, and supply chain management [26]. By harnessing AI capabilities, stakeholders in the agricultural sector can make data-driven decisions to optimize resource use, mitigate risks, and enhance overall productivity [11].

However, alongside the potential benefits, the adoption of AI in agriculture also brings forth a set of challenges and ethical considerations that must be addressed [13]. Issues such as data privacy, algorithmic bias, and socio-economic implications underscore the importance of taking a holistic approach to AI deployment in agriculture [14]. Therefore, a comprehensive understanding of both the opportunities and challenges associated with AI in agriculture is essential for ensuring its responsible and sustainable integration into agricultural systems.

Literature Reviews

A comprehensive literature review was conducted to gather existing knowledge and insights regarding the application of artificial intelligence (AI) in various aspects of agriculture. Academic databases such as PubMed, IEEE Xplore, ScienceDirect, and Google Scholar were searched using relevant keywords, including "AI in agriculture," "precision farming," "crop monitoring," "pest and disease detection," "yield prediction," "irrigation optimization," "fertilization optimization," and "supply chain management in agriculture." Peer-reviewed journals, conference papers, books, and reports were examined to collect relevant information on the topic.

S. No.	Name of The Author and Year Of Publication	Objective of The Research Paper	Conclusion and Findings of the Research Paper
1.	JialiZha, 2020	The review explores the intersection of AI and agriculture, focusing on soil management, weed management, and IoT utilization. It aims to highlight challenges such as uneven mechanization distribution, security concerns, and algorithm flexibility.	AI technology in agriculture addresses challenges like decreasing manual labor, limited arable land, and food scarcity. Scientists worldwide have developed AI solutions, focusing on soil and weed management, as well as IoT applications. However, practical challenges include uneven technology distribution, transitioning AI to real-world environments, data handling, and security concerns.
2.	ManasWakchaure, B.K. Patel, A.K. Mahindrakar, 2022	The main aim of the proposed investigation is to carry out a systematic study of AI techniques in the field of agriculture. The proposed study considers twelve popular AI techniques according to their wide adoption in agriculture and existing papers available such as fuzzy logic, genetic algorithm, neural network, particle swarm optimization, ant colony optimization, firefly algorithm, bat algorithm, artificial potential field approach, artificial bee colony algorithm, harmony search algorithm, cell decomposition, and simulated annealing.	The proposed work delves into various AI techniques (such as fuzzy logic, artificial neural networks, genetic algorithms, and more) applied in agriculture. It specifically focuses on expert systems, agricultural robots, and sensor technology for data collection and transmission. Notably, the study examines three critical phases: Cultivation, Monitoring, and Harvesting. By analyzing over 150 papers from 1960 to 2021, the research sheds light on the potential impact of AI in agriculture and identifies future research gaps.
3.	Dr. P.M. Durai Raj Vincent, Dr. Deepa N, Mrs. Dhivya Elavarasan, Prof. Kathiravan Srinivasan, Prof. Sajjad Hussain Chaudhary, Dr. Celestine Iwendi, 2019	The research addresses the challenge of increasing agricultural productivity in the face of population growth and limited arable land. It proposes an expert system that uses wireless sensor networks and IoT devices to collect and process farm data. The system integrates AI techniques such as neural networks and MLP to assess the suitability of land for cultivation based on four decision classes.	The work proposes a model that uses MLP with four hidden layers to process sensor data and assess the suitability of land for cultivation based on four decision classes. The model achieves 99% accuracy and precision and provides precise guidance to farmers on crop selection and management. The work demonstrates the potential of multiclass classification over binary classification for improving agricultural productivity and efficiency.
4.	Shivangi Sharma, Kirti Verma, Palak, Hardaha	Agricultural automation, driven by AI, has revolutionized farming practices worldwide. As the global population grows, the demand for food and labor increases. Traditional farming techniques fall short, prompting the development of automated solutions. These innovations address challenges such as weather variability, labor shortages, and food security concerns transforming agriculture by managing pests, controlling weeds, and optimizing irrigation.	AI's integration into agriculture has transformed farming practices, addressing challenges like labor shortages and food security. From precise irrigation management to weed control and pest monitoring, AI enhances efficiency and sustainability. The future lies in combining AI with other technologies for sustainable farming. AI-powered sensors and algorithms maximize crop yields and preserve resources by optimizing water usage. AI-equipped robotics and drones find and remove weeds, cutting down on the need for pesticides. AI-driven pest management solutions reduce the need for pesticides by enabling early identification and focused actions. AI's promise to improve sustainable farming methods and reduce environmental effects is further enhanced by ongoing research into automated weeding strategies and

			soil water sensing.
5.	A.S. Noor Nawaz, Hasansab A. Nadaf, Abdul Kareem M. and Nagaraja H.	To explore that AI is transforming Indian agriculture by promoting the use of emerging technologies or not. The issues associated with food production for an expanding population will be addressed by industries pushing machine learning and AI technologies or not, particularly in automation, drones, and agriculture. .	Applications of AI such as machine vision, speech recognition, and expert systems are essential. Acceptance of AI is influenced by government policies. Despite worries about jobs, human intellect is still crucial for AI development. Key applications include: 1. Autonomous Tractors: AI-enabled machines perform multiple tasks, saving time and labor. 2. Resource Optimization: AI enhances decision-making, optimizing resource utilization. 3. Regional Adaptation: Innovations cater to diverse climatic conditions. 4. Job Concerns: While AI saves labor, addressing job displacement remains crucial. In summary, AI holds immense potential for sustainable and efficient farming in India
6.	C. Popa, 2011	This study discusses the significant challenges faced by agriculture, including the need to increase production by 70% over the next 50 years amidst limited resources and climate change. It highlights the potential of Artificial Intelligence (AI) as a solution, with some opinions suggesting that humanity will merge with AI, marking a new phase of evolution.	AI has a lot to offer the agricultural industry, including increased crop yields, lower costs, better resource management, and environmental resilience. But it's important to pay close attention to ethical issues like abuse concerns, equal access, and human-machine interaction. The study highlights how AI has the potential to revolutionize agriculture, but it also stresses how responsible its application must be. The study also acknowledges the current lack of access to basic resources for millions of people. It explores the adoption trends and development of AI agents in agriculture, with a focus on expert systems, data-collecting sensors, and agricultural robots, aiming to understand their potential impact in this field.
7.	Suraj Panpatte, C. Ganesh Kumar, 2021	A possible summary of the study is: The study explores the impact of artificial intelligence (AI) on agriculture in India, a sector that faces many challenges due to population growth, climate change, and resource scarcity. It focuses on the case of Blue River Technology.	The paper explores the effects of AI on Indian agriculture, with particular attention to yield optimization and weed control methods offered by Blue River Technology. It evaluates the SWOT and PESTEL elements affecting the business's operations. Although AI has the potential to improve sustainability and efficiency, its successful integration will depend on policy, stakeholder collaboration, and education.

8.	Vignesh Kumar Vijaya kumar, Nagaraj Bala krishnan	This paper discusses the application of Artificial Intelligence (AI) in agriculture automation, specifically using data from Wireless Sensor Network (WSN) technology. The WSN collects, accounts, and analyzes data for monitoring agricultural activities.	The use of Wireless Sensor Network (WSN) data is the main topic of this paper's investigation of AI's involvement in agricultural automation. WSN collects and evaluates environmental data that is essential for keeping an eye on farming operations. Artificial Neural Networks (ANN) in particular, when integrated with AI, maximize automation intelligence. Compared to previous systems, the Generalized Regression Neural Network (GRNN) performs exceptionally well, attaining an accuracy rate of 95%. Together, they protect the environment and help farmers achieve their goals.
9.	Nikolaos L. Tsakiridis, Themistoklis Diamantopoulos, Andreas L. Symeonidis, John B. Theocharis, Athanasios Iossifides, Periklis Chatzimisios, George Pratos & Dimitris Kouvas	In response to the challenges of costly and opaque IoT systems in agriculture, we introduce Vital. Vital integrates affordable sensors, a reliable data repository, and a crucially important feature: an explainable AI decision support system. By generating interpretable fuzzy rule bases, Vital enables automated field irrigation while ensuring trustworthiness. Through pilot testing, we validate Vital's effectiveness in monitoring open-field setups, offering a promising solution for modern agriculture.	Our paper introduces Vital, an IoT-based system for field monitoring and automated irrigation in agriculture. Vital combines cost-effective sensors with robust data infrastructure and employs a fuzzy-rule-based approach for irrigation decisions, ensuring interpretability through explainable AI. Future directions include expanding sensor types and valve functionalities, as well as evaluating the system's performance under missing data scenarios and comparing it with alternative approaches. Overall, Vital presents a promising solution for enhancing efficiency and reliability in agricultural practices.
10.	Anu Jose, S. Nandagopalan, Chandra Mouli Venkata Srinivas Akana	This article examines the potential of AI-powered solutions to address the challenges posed by the projected increase in global population and limited agricultural land. It provides an overview of various AI, machine learning, and deep learning techniques applied in agriculture to enhance crop yield and quality while optimizing resource utilization. The review evaluates existing studies, discusses available products and services for farmers, and highlights both the opportunities and obstacles in AI-driven agriculture.	This study highlights the critical role that technology plays in advancing profitable and productive sustainable farming. Farmers may implement resource-efficient practices, monitor the impacts of climate change, and quickly respond to pest and disease risks by utilizing artificial intelligence, machine learning, and deep learning. The review offers a comprehensive analysis of the advantages, drawbacks, and present state of these strategies in agriculture. It also points out areas that need more research, especially in precision agriculture, and provides suggestions for future paths. In the end, the study emphasizes how technology may be a transforming tool in tackling the ever-changing problems associated with agricultural sustainability.
11.	DR. BEATRICE GARSKEM, ANTONIA BAU, PROF. FELIX EKARDT	The article examines how digitalization in agriculture, crucial for sustainability, aligns with environmental goals like those in the Paris Agreement.	For agriculture to contribute significantly to climate and biodiversity targets, digital innovations and AI must be aligned with environmental goals. This requires a legal framework ensuring fair access and safe use of technology, with adaptations for AI-specific characteristics. Data privacy and security, along with the Common European agriculture data space, are

			vital. The Common Agricultural Policy should prioritize linking digitalization with environmental protection while avoiding rebound effects. Digitalization can enhance sustainability if designed to meet environmental objectives, complemented by effective instruments aligned with global agreements like the Paris Agreement and the Convention on Biological Diversity.
12.	FAISAL KARIM SHAIKH, MOHSIN ALI MEMON, NEEM AHMED MAHOTO SHERALI ZEADALLY, JAMEL NEBHEN	Paper review underscores the superiority of deep learning algorithms over conventional machine learning methods, owing to their ability to process extensive datasets and make timely, intelligent decisions akin to human cognition.	In conclusion, the integration of artificial intelligence (AI) into smart agriculture represents a significant step towards ensuring sustainability in the agricultural sector. By leveraging AI techniques across various domains such as soil and irrigation management, weather forecasting, plant growth, disease prediction, and livestock management, agriculture can achieve more efficient and effective practices. Our review underscores the superiority of deep learning algorithms over conventional machine learning methods, owing to their ability to process extensive datasets and make timely, intelligent decisions akin to human cognition. Moving forward, future research should continue to explore innovative AI approaches to address evolving challenges and further enhance the sustainability and productivity of agriculture.
13.	HARSHIT MISHRA, AND DIVYANSHI MISHRA	This article underscores the vital role of technology, particularly Artificial Intelligence (AI) and Machine Learning (ML), in revolutionizing agriculture. It highlights how AI and ML have transformed various aspects of farming, including crop production, animal husbandry, and forestry. These technologies address challenges such as resource limitations and climate change, promoting increased productivity, precision farming, and efficient resource management. AI and ML facilitate crop monitoring, predictive analytics, and livestock management, promising enhanced productivity, sustainability, and data-driven decision-making in agriculture.	In summary, while the overall quantity of toxic metals in soil may not decrease with biochar addition, it effectively reduces the mobility and bioavailability of key metals like Pb, Cr, and Cd, while enhancing soil quality and nutrient availability. Biochar's impact on soil physical properties influences plant growth positively. Moreover, it reduces the leaching of resources and enhances nutrient retention. In contaminated water and soil remediation, biochar proves to be a viable and eco-friendly solution. Its adeptness in adsorbing toxic metals and pollutants makes it a promising method for environmental cleanup, offering both environmental benefits and economic viability. Thus, biochar presents itself as a valuable tool in mitigating environmental contaminants in soil and water systems, contributing to sustainable environmental management practices.
14.	FILBERT H. JUWONO, W.K. WONG, SEEMA VERMA, NEHA SHEKHAWAT, BASIL ANDY LEASE, CATUR APRIONO	This paper aims to give a complete overview of crop-weed detection from an Agriculture 5.0 point of view This paper discusses an in-depth review of Machine Learning (ML) techniques used for discriminating weeds from crops or plants. We specifically	Agriculture 5.0 is an emerging concept where sensors, big data, Internet-of-Things (IoT), robots, and Artificial Intelligence (AI) are used for agricultural purposes. Different from Agriculture 4.0, robots and AI have become the focus of the

		present a detailed explanation of the five steps required in using ML algorithms to distinguish between weeds and plants. Various techniques employing ML have been investigated in this paper. Researcher presented an overview of crop and weed recognition or discriminating algorithms.	implementation in Agriculture 5.0. One of the applications of Agriculture 5.0 is weed management where robots are used to discriminate weeds from the crops or plants so that proper action can be performed to remove the weeds. The biggest problem is how the technology is used, followed by the ways used owing to crop and weed morphology. As a result, determining which techniques are preferable on an "apple-to-apple" basis is extremely challenging. In this regard, stakeholders may consider implementing ways that are most comparable to benefit from proven outcomes.
15.	VICTOR MOKAYA	In this paper discussion is on the future of precision agriculture which has been proven to work in other countries using machine learning & artificial intelligence. The scope of utilization is focused on medium and large-scale farmers to point out the advantages and disadvantages of the techniques.	Precision agriculture remains a wishful concept in many developing countries. It is possible to achieve the above vision in India to improve the food security and per capita income of the farmers. The above-mentioned challenges and promising solutions are predictions of the future landscape of Indian agriculture. Technological advancements and government initiatives to foster and promote precision agriculture through aid, reliefs, tax holidays, and other incentives to farmers will greatly attract investment. This move will thus help deliberate efforts to protect the growth and sustainability of future generations yet to come. Previously there has been slow growth in this sector but from the year 2016 onwards many start-ups have been emerging that are yielding high investments. These cognitive technologies have been applied in advanced countries and have resulted in increased yield, growth in GDP, low mortality rates, and improved living standards. The same can be applied locally to boost production in the agricultural sector.
16.	DR. SEBASTIAN KUJAWA, PROF. DR. GNIEWKO NIEDBAŁA	The papers presented in this Special Issue cover a wide range of applications of various types of artificial neural networks in agriculture. This Special Issue aimed to highlight top-tier research on neural network applications across diverse agricultural challenges.	Artificial neural networks, pivotal in machine learning and AI, draw inspiration from the human brain's structure. They find extensive application in agriculture, aiding in production forecasting, disease verification, weed control, and crop quality classification. These networks support decision-making, optimize processes like storage and transport, and predict management costs, driving the adoption of AI tools in precision farming and digital agriculture.
17.	GARIMA SINGH, ANAMIKA SINGH, GURJIT KAUR	The agricultural industry relies on innovative ideas and technological advancements to help increase yields and better allocate resources. The late	In conclusion, the agricultural sector has historically thrived on innovation, with mechanical advancements of the late 19th and 20th centuries

		19th and 20th centuries brought several mechanical innovations, like tractors and harvesters. Today, a driving force behind increased agricultural production at a lower cost is artificial intelligence and the Internet of Things, which leaves the door wide open for engineers looking to give new innovative ideas to enhance the agricultural yield with fewer resources.	revolutionizing production. Today, the integration of artificial intelligence and the Internet of Things marks a new era of efficiency and sustainability in agriculture. These technologies enable precise resource allocation and yield optimization, empowering engineers to develop innovative solutions for enhancing productivity while minimizing resource usage. As we continue to embrace technological advancements, the agricultural industry is poised to meet the growing demands for food production more sustainably and cost-effectively, ensuring a brighter future for global food security.
18.	Amit Sharma, Ashutosh Sharma, Alexey Tselykh, Alexander Bozhenyuk, Tanupriya Choudhury, Madani Abdu Alomar, Manuel Sánchez-Chero	In particular, precision farming (PF) and precision agriculture (PA) are examined in this study as examples of how artificial intelligence (AI) and the Internet of Things (IoT) are revolutionizing modern agriculture.	It draws attention to how crucial a role they play in improving yields, profitability, and precision. Excellent performance metrics are demonstrated by a suggested approach, which has a recall rate of 97.65%, accuracy of 98.65%, and precision of 98.32%. The paper shows the breakthroughs made possible by AI and IoT in agriculture by offering insights into necessary tools, and techniques. The study also details essential equipment, methods, and real-time tools utilized in PF and PA, providing insights into the transformative impact of AI and IoT on contemporary agricultural practices.

RESEARCH METHODOLOGY

Objective: This review aims to explore the potential of harnessing artificial intelligence (AI) for agricultural advancement based on the existing literature Review.

Data Collection: Data on AI applications in agriculture were gathered from a variety of sources, including academic publications, industry reports, and government publications. Literature focusing on the use of AI in agricultural contexts was compiled to offer a thorough overview of the topic.

Data Analysis: Qualitative analysis techniques, such as content analysis and thematic analysis, were employed to organize and interpret the data to identify common themes, trends, challenges, and opportunities associated with AI adoption in agriculture.

Synthesis: The findings from the literature review and data analysis were synthesized to develop a coherent narrative on the current state, challenges, and opportunities of applying AI techniques in agriculture. Key insights and recommendations were identified based on the synthesized information to inform future research, policy, and practice in this domain.

Limitations: The limitations of the study were that research discussions are based upon the existing literature review. Efforts were made to mitigate these limitations through rigorous research methods and transparent reporting of findings.

Overall, the methodology employed in this research aimed to provide a rigorous and comprehensive examination of the application of AI in agriculture, considering both the opportunities and challenges associated with its adoption.

DISCUSSION

Artificial intelligence (AI) holds significant promise in revolutionizing various facets of agriculture, offering transformative solutions to enhance productivity, sustainability, and resilience. This comprehensive review explores the burgeoning applications of AI techniques across critical domains of agricultural production and management [9]. From crop monitoring to supply chain management, AI leverages diverse data sources such as sensors, drones, and satellite imaging to provide actionable insights for stakeholders [27,19]. By enabling precise and timely monitoring of crop health and growth, AI

facilitates informed decision-making to address challenges like nutrient deficiencies and water stress, thus optimizing agricultural operations in dynamic environments [18]. Moreover, AI's prowess extends to pest and disease detection, offering efficient and cost-effective solutions compared to traditional methods reliant on manual inspection and laboratory analysis [20]. Yield prediction, irrigation, and fertilization optimization benefit from AI's ability to analyze complex datasets and derive predictive models, ultimately bolstering food security and sustainability [28,21]. However, alongside its promises, the ethical, social, and environmental implications of AI integration in agriculture necessitate careful consideration and responsible deployment to ensure equitable and sustainable outcomes for all stakeholders [13,14]. Through a comprehensive examination of AI's multifaceted role in agriculture, this review aims to shed light on its potential to address pressing challenges while navigating ethical complexities and promoting inclusive development.

A. CROP MONITORING

Crop monitoring, which is essential for improving agricultural operations, was once done by hand and was prone to errors and inefficiencies [29]. However, the development of AI offers a revolutionary remedy [30]. AI makes it possible to monitor crops extensively and on a wide scale by utilizing a variety of data sources, including sensors, drones, and satellite imaging [27]. Artificial Intelligence (AI) can quickly evaluate large datasets to derive valuable insights about crop health, development, and possible problems like nutrient shortages or water stress [18]. AI is capable of this thanks to sophisticated machine learning techniques like deep learning [8]. AI helps farmers, agronomists, researchers, and policymakers make data-driven choices that improve productivity, sustainability, and profitability in agriculture by supplying precise, unbiased, and timely information [26]. This paradigm-shifting use of AI for crop monitoring provides scalable, accurate, and useful insights for efficient agricultural management in a constantly changing environment [9].

B. Pest and Disease Detection

Diseases and pests seriously jeopardize crop productivity and health, which affects farmers and the environment [31]. Traditional approaches to pest and disease identification and detection, which rely on laboratory analysis and manual inspection, are expensive, time-consuming, and frequently fall short of capturing the dynamic nature of disease and pest incidence [32]. Artificial intelligence (AI) offers a more effective solution by analyzing crop signals and photos using data from various sources such as sensors, drones, and satellite imaging [19]. AI can quickly identify illnesses and pests using machine learning, especially deep learning, which enables quick, precise, and affordable detection and identification [33]. AI gives stakeholders the ability to respond more effectively to pest and disease concerns by allowing data-driven diagnostic and treatment suggestions, which increases crop resilience and output in agriculture [26].

C. Yield Prediction

In agricultural planning and decision-making, yield prediction is essential because it helps farmers, agronomists, researchers, and policymakers maximize productivity and guarantee food security [34]. Yield prediction, which has historically relied on statistical models, is constrained by a lack of data, suppositions, and flexibility [35]. AI provides a more advanced method by utilizing a variety of data sources, including sensors and satellite photography, to identify the many variables that affect yield [28]. Artificial Intelligence creates complicated models that can capture nuanced interactions and dynamics through machine learning, especially deep learning [8]. Artificial Intelligence (AI) enables stakeholders to successfully solve yield gaps by facilitating data-driven analysis and risk assessment through the provision of precise and timely predictions [36]. This cutting-edge AI-driven method aims to improve yield prediction's accuracy and usefulness, promoting lucrative and sustainable agriculture while tackling the issue of food security [25].

D. Irrigation and Fertilization Optimization

Although they are essential to agricultural development, fertilization, and irrigation provide difficulties because of their intricacy and effects on the environment [1]. Precise information and flexible management are necessary to reach optimal levels [21]. By utilizing a variety of data sources to track crop water and nutrient status and suggest modifications, artificial intelligence (AI) offers a possible answer [22]. Artificial intelligence (AI) can analyze data to optimize fertilization and irrigation schedules, maximizing production while minimizing expenses and environmental impact [9]. These approaches include deep learning and reinforcement learning [7]. AI makes data-driven decisions that improve water and nutrient use efficiency and conservation possible by giving stakeholders customized guidance [11]. There is a lot of promise for sustainable agriculture with this AI integration into fertilization and irrigation management, which addresses both environmental and productivity issues [26].

Based on the literature review it can be concluded that Microbial fertilizers play a very important role for the sustainable soil health.

Sustainable Soil Health: Microbial fertilizers improve soil health by encouraging beneficial microbial populations. These microorganisms enhance soil structure, nutrient availability, and overall fertility. In contrast to chemical fertilizers, which can degrade soil quality over time, microbial fertilizers contribute to long-term soil sustainability.

Reduced Environmental Impact: Chemical fertilizers' synthetic composition can pollute the air and groundwater. In contrast, microbial fertilizers are environmentally friendly and do not contribute to harmful pollution. Using microorganisms reduces the environmental footprint associated with conventional fertilizers.

Nutrient Conversion: Microbes play an important role in converting insoluble nutrients (such as nitrogen, phosphorus, and potassium) into plant-usable forms. They degrade organic matter, making nutrients more available to crops. This nutrient conversion process promotes healthy plant growth and increases crop yield. Microbial fertilizers are more cost-effective than chemical fertilizers. Farmers can make them on-site, which eliminates the need for costly external inputs. Furthermore, microbial fertilizers are renewable and sustainable sources of nutrients for crops.

Plant Health and Immunity: Microbes interact with crop plants to improve their immunity, growth, and yield. They protect plants from pests and diseases, which improves overall crop health. Healthy plants are more resilient and productive.

E. Precision Farming

Precision farming takes temporal and geographical variability into account to maximize crop inputs and outputs [37]. Artificial Intelligence uses data from many sources, such as sensors, drones, and satellites, to deliver insights in real time [30]. AI increases production, lowers costs, and promotes sustainability by providing site-specific suggestions for seeds, fertilizers, and pesticides through the use of machine learning [9]. AI-driven robots also make it possible to precisely execute suggestions, which increases productivity even further [23]. By utilizing data-driven solutions, the incorporation of AI into precision farming transforms crop management and optimization for all involved parties [17].

F. Supply Chain Management

Supply chain management is the process of planning, coordinating, and controlling the flow of agricultural products, from the production stage to the consumption stage, across different actors and activities, such as harvesting, processing, packaging, storing, transporting, distributing, and retailing [38]. Supply chain management can help farmers and agribusinesses to optimize the quality, quantity, and cost of their products, and to meet the demand and preferences of the consumers and the market [39]. Supply chain management can also help consumers and society ensure the safety, traceability, and sustainability of the food they consume [40]. AI can improve and innovate supply chain management, by using various sources of data, such as satellite imagery, drones, sensors, and smartphones, to monitor and track the location, condition, and movement of agricultural products along the supply chain [10]. AI can also use machine learning techniques, such as deep learning and reinforcement learning, to learn from the data and provide optimal decisions and actions for supply chain planning and control, such as inventory management, demand forecasting, routing and scheduling, pricing and bidding, and quality assurance [9]. AI can also use blockchain and smart contract technologies, such as Ethereum and Hyperledger, to provide secure, transparent, and decentralized platforms for supply chain information and transaction sharing and verification [30]. AI can thus provide supply chain management information and solutions to the stakeholders, and enable data-driven traceability, quality control, and market intelligence [9].

G. Ethical, Social, and Environmental Implications

Adopting AI in agriculture raises several social, ethical, and environmental issues [15]. Although it has many advantages, such as higher productivity and sustainability, it also brings up issues with privacy, prejudice, job displacement, and the health of the ecosystem [41]. Development and use of AI in agriculture must be done responsibly, which means moral standards centered on privacy, responsibility, and justice must be established [15]. Incorporating stakeholders into decision-making procedures guarantees fair access to information and promotes openness [42]. Responsible innovation is encouraged by ongoing assessments of AI's effects on the social, economic, and environmental spheres [15]. Initiatives to raise awareness and educate stakeholders are essential to enable them to successfully negotiate the challenges of AI integration in agriculture [15]. These guidelines and inclusive communication can let AI be used to solve urgent agricultural issues while maintaining the values and interests of all involved parties [15].

CONCLUSION

In this article, we have provided a comprehensive review of the current state, challenges, and opportunities of applying AI techniques to various aspects of agricultural production and management. We have covered crop monitoring, pest and disease detection, yield prediction, irrigation and fertilization optimization, precision farming, and supply chain management. We have also discussed the ethical, social, and environmental implications of AI adoption in agriculture, and provided some recommendations for ensuring responsible and inclusive AI development and deployment.

AI has the potential to transform agriculture, by providing data-driven, intelligent, and automated solutions that can enhance agricultural productivity, efficiency, sustainability, and resilience. AI can also contribute to the achievement of the SDGs related to agriculture, such as ending hunger, ensuring food security, promoting sustainable agriculture, and combating climate change. However, AI also poses some challenges and risks for agriculture, such as data quality, privacy, security, bias, fairness, accountability, transparency, explainability, and human-machine interaction. AI also raises some ethical, social, and environmental questions, such as the impact of AI on labor, livelihood, culture, biodiversity, and human dignity.

Future Directions

There is a need for further research and development of AI in agriculture, that can address the existing and emerging challenges and risks, and that can leverage the existing and emerging opportunities and benefits. Some possible future directions and challenges for AI research and development in agriculture are:

- ✓ Developing and applying new and advanced AI techniques, such as generative adversarial networks, graph neural networks, and natural language generation, that can improve the performance, robustness, and creativity of AI solutions for agriculture.
- ✓ Integrating and combining different sources and types of data, such as multispectral, hyperspectral, thermal, and radar imagery, and text, audio, and video data, can provide more comprehensive and diverse information and insights for agriculture.
- ✓ Exploring and exploiting new and emerging domains and applications of AI in agriculture, such as vertical farming, urban farming, aquaculture, and agroforestry, that can offer new possibilities and value for agriculture.
- ✓ Evaluating and validating the impact and outcome of AI in agriculture, using rigorous and reliable methods and metrics, such as randomized controlled trials, cost-benefit analysis, and life cycle assessment, that can provide evidence and feedback for AI improvement and adoption.
- ✓ Engaging and collaborating with the stakeholders and the public, using participatory and inclusive methods and platforms, such as citizen science, crowdsourcing, and co-creation, that can ensure that AI is responsive and accountable to the needs and preferences of the users and society.

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Conflict of Interest

None

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Ethics Statement

Throughout the research process, ethical considerations were taken into account, particularly concerning the use of data and the potential impact of AI technologies on stakeholders and the environment. Efforts

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Informed Consent
Not applicable

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