

The Role of Artificial Intelligence in Addressing Future Challenges in Food Production and Sustainability

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Article Info ABSTRACT

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Artificial Intelligence Climate Resilience Precision Agriculture Resource Management **Objective**: This collection of articles examines the role of artificial intelligence (AI) in transforming the farming and agricultural industries in response to global challenges such as rapid population growth, diminishing farmland, and climate change.

Methods: The articles synthesize current research and case studies that illustrate the implementation of AI technologies in agricultural practices. They analyze how AI can enhance productivity, operational efficiency, and sustainability in agriculture, while addressing the evolving demands of the market and environmental conditions.

Results: The findings indicate that AI has significant potential to revolutionize agricultural production systems by improving output, increasing operational efficiency, and fostering resilience against climate variability. The integration of AI technologies can lead to more sustainable agricultural practices that meet the needs of a growing global population projected to exceed nine billion by 2050.

Conclusions: This body of work contributes to the existing literature by highlighting the transformative effects of AI in agriculture, emphasizing its necessity for future food security, and providing insights into the challenges and opportunities that lie ahead in the agricultural sector.

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1- Introduction

The intersection of technology and agriculture has become increasingly critical as the world faces unprecedented challenges related to food security, environmental sustainability, and economic viability. The Food and Agriculture Organization (FAO) of the United Nations has projected that the global population will exceed nine billion by the year 2050, a demographic shift that will place immense pressure on agricultural systems worldwide. This burgeoning population, coupled with the realities of shrinking arable land, dwindling natural resources, erratic climatic fluctuations, and evolving market demands, necessitates a radical transformation of agricultural practices. In this context, the emergence of artificial intelligence (AI) offers a promising avenue for enhancing agricultural productivity and sustainability, thereby addressing the multifaceted challenges of modern farming.

The agricultural sector has historically been characterized by its reliance on traditional practices and labor-intensive methods. However, as the demands on food production systems escalate, there is an urgent need for innovative solutions that can optimize resource use, increase yields, and improve resilience against environmental stressors. The concept of a "new agricultural paradigm" emerges from this necessity, one that is defined by increased efficiency, operational sustainability, and adaptability to changing conditions. AI technologies, including machine learning, data analytics, and robotics, are positioned at the forefront of this transformation, offering tools that can revolutionize how farming is conducted.

Al's potential to enhance agricultural productivity can be understood through several key applications. For instance, precision agriculture, which utilizes AI-driven data analysis and sensor technologies, allows farmers to monitor crop health, soil conditions, and weather patterns in real time. This data-driven approach enables more informed decision-making, leading to optimized inputs such as water, fertilizers, and pesticides, ultimately resulting in higher yields with reduced environmental impact. Furthermore, AI can facilitate predictive analytics, allowing farmers to anticipate and respond to potential challenges such as pest infestations or adverse weather events, thereby reducing losses and increasing resilience.

Moreover, AI's ability to process vast amounts of data can enhance supply chain efficiency in the agricultural sector. By analyzing market trends and consumer preferences, AI can help farmers make better decisions regarding crop selection, planting schedules, and distribution strategies. This responsiveness to market dynamics not only improves profitability for farmers but also contributes to overall food security by ensuring that agricultural production aligns with consumer needs.

However, the integration of AI into agriculture is not without its challenges. The digital divide between

developed and developing regions poses a significant barrier to the widespread adoption of AI technologies in farming. While advanced economies may have the resources and infrastructure to implement AI solutions effectively, many smallholder farmers in developing countries lack access to the necessary technology, training, and financial support. This disparity raises important questions about equity and inclusivity in the agricultural sector, as well as the potential risks of exacerbating existing inequalities.

Furthermore, the ethical implications of AI in agriculture warrant careful consideration. Issues related to data privacy, algorithmic bias, and the potential displacement of labor must be addressed to ensure that the benefits of AI are realized in a manner that is socially responsible and equitable. As AI systems are increasingly deployed in agricultural contexts, it is essential to engage stakeholders from various sectors—including farmers, policymakers, technologists, and ethicists—in discussions about the responsible use of these technologies.

The role of government policy and investment in promoting AI adoption in agriculture cannot be overlooked. Policymakers must create an enabling environment that fosters innovation while also addressing the socioeconomic challenges faced by farmers. This includes investing in research and development, providing training and resources for smallholder farmers, and establishing regulatory frameworks that promote transparency and accountability in AI applications.

In addition to these considerations, the environmental implications of AI in agriculture must be examined. While AI has the potential to enhance resource efficiency and reduce waste, it is crucial to ensure that the technologies employed do not inadvertently contribute to ecological degradation. Sustainable practices must be at the core of AI applications in agriculture, aligning technological advancements with the principles of environmental stewardship and conservation.

The articles in this collection delve into these themes, exploring the diverse ways in which AI is being utilized in the farming and agricultural industries. They highlight innovative case studies, examine the challenges and opportunities associated with AI adoption, and propose frameworks for ensuring that the integration of AI into agriculture is both effective and equitable. By synthesizing insights from various perspectives, this body of work aims to contribute to a deeper understanding of the role of AI in shaping the future of agriculture.

As we navigate this new agricultural paradigm, it is essential to remain vigilant about the potential pitfalls and challenges that accompany technological advancement. The journey toward a more efficient, resilient, and sustainable agricultural system will require collaboration, innovation, and a commitment to social responsibility. The promise of AI in agriculture is significant, but its successful

implementation will depend on our ability to address the complex interplay of technological, economic, and ethical factors that shape the agricultural landscape.

In conclusion, the integration of artificial intelligence into the agricultural sector represents a transformative opportunity to enhance food production and sustainability in the face of global challenges. As we look toward the future, it is imperative that we harness the power of AI in a manner that is inclusive, equitable, and environmentally responsible, ensuring that the benefits of these technologies are shared by all stakeholders in the agricultural ecosystem. The articles that follow will provide valuable insights into the current state of AI in agriculture, the challenges that lie ahead, and the potential pathways for fostering innovation and sustainability in this vital sector.

Literature Review

The integration of Artificial Intelligence (AI) into the agricultural sector has emerged as a critical area of research, particularly in light of the pressing challenges posed by global population growth, resource scarcity, and climate change. The Food and Agriculture Organization (FAO) of the United Nations projects that the world population will exceed nine billion by 2050, necessitating a transformation in agricultural practices to enhance productivity while ensuring sustainability (FAO, 2017). This literature review synthesizes current research on the applications of AI in agriculture, focusing on its potential to revolutionize farming practices and address the multifaceted challenges that the sector faces.

Population Growth and Agricultural Demand

As the global population continues to rise, the demand for food is expected to increase significantly. According to Godfray et al. (2010), feeding a growing population will require a 70% increase in food production by 2050. This challenge is compounded by the reduction of arable land due to urbanization and environmental degradation (Tilman et al., 2011). Consequently, there is an urgent need for innovative solutions that can enhance agricultural productivity without further straining natural resources.

The Role of AI in Agriculture

AI technologies have the potential to address these challenges by improving efficiency, increasing yields, and promoting sustainable practices. AI applications in agriculture can be broadly categorized into several domains, including precision agriculture, predictive analytics, and autonomous systems (Wolfert et al., 2017).

Precision Agriculture

Precision agriculture involves the use of AI to analyze data from various sources, such as satellite imagery, soil sensors, and weather forecasts, to optimize farming practices (Zhang & Wang, 2019). This approach allows farmers to make data-driven decisions, enhancing crop management and resource allocation. For instance, AI

algorithms can predict the optimal time for planting and harvesting, thereby maximizing yields (Liakos et al., 2018). Additionally, precision agriculture facilitates the efficient use of water and fertilizers, reducing waste and minimizing environmental impact (Mulla, 2013).

Predictive Analytics

Predictive analytics powered by AI can help farmers anticipate market trends, pest outbreaks, and disease spread. By analyzing historical data and current conditions, AI models can provide insights that enable proactive decision-making (Kamilaris & Prenafeta-Boldú, 2018). For example, machine learning algorithms can identify patterns in crop performance and environmental conditions, allowing farmers to adjust their practices in real-time (Chlingaryan et al., 2018). This capability is vital in a rapidly changing agricultural landscape, where adaptability is essential for resilience.

Autonomous Systems

The development of autonomous systems, such as drones and robotic harvesters, represents another significant advancement in agricultural technology. These systems, often powered by AI, can perform tasks such as planting, monitoring, and harvesting with minimal human intervention (Shamshiri et al., 2018). The use of drones for crop surveillance, for example, allows for precise monitoring of field conditions, enabling timely interventions that can prevent crop loss (Zhang et al., 2016). Furthermore, autonomous machinery can operate around the clock, increasing overall efficiency and productivity.

2- Materials and Methods

The research employs a mixed-methods design, consisting of three phases: a literature review, case studies, and empirical data collection through surveys and interviews.

- A. Literature Review: The initial phase involves reviewing peer-reviewed articles, industry reports, and white papers from 2010 to 2023 to establish a theoretical framework on AI in agriculture. It focuses on the evolution of AI technologies, successful implementations, impacts on productivity and sustainability, and barriers to adoption.
- B. Case Studies: The second phase analyzes selected case studies showcasing successful AI applications in diverse agricultural settings. A structured framework evaluates the context, AI technologies used, outcomes, and challenges faced, providing real-world examples of AI's potential to address agricultural challenges.
- C. Empirical Data Collection: The final phase involves surveys and semi-structured interviews with stakeholders, including farmers and policymakers. Surveys collect quantitative data on AI awareness, usage, benefits, and challenges, while interviews

provide qualitative insights into personal experiences and support needed for AI adoption.

Data analysis combines quantitative methods using statistical software and qualitative thematic analysis to identify patterns and insights. Ethical considerations ensure participant consent and confidentiality, while limitations acknowledge potential biases and the evolving nature of AI.

3-Results and Discussion

In recent decades, the integration of AI into agricultural practices has garnered considerable attention due to its potential to revolutionize farming methods and enhance food production efficiency. The application of AI technologies facilitates data-driven decision-making and optimizes resource allocation, enabling farmers to achieve higher yields with fewer inputs. Various AI methodologies, including machine learning, computer vision, and robotics, are employed to improve precision agriculture, pest management, and predictive analytics.

Precision agriculture is one of the most notable advancements facilitated by AI. Through the use of satellite imagery, drones, and sensors, farmers can collect and analyze vast amounts of data regarding soil health, crop conditions, and environmental factors. Machine learning algorithms can process this data to identify patterns and provide actionable insights, thus empowering farmers to make informed choices on fertilization, irrigation, and crop rotation. Such targeted approaches not only increase crop yield but also reduce the environmental impact of traditional farming practices by minimizing excess chemical usage and conserving water.

Moreover, AI is increasingly being leveraged in pest management strategies. By employing computer vision technologies, farmers can monitor pest populations in real-time, allowing for timely interventions that target specific issues without resorting to blanket pesticide applications. This precision not only preserves beneficial insect populations but also reduces the likelihood of herbicide resistance developing among pests.

The climate resilience of agricultural systems is another area where AI can play a critical role. Predictive analytics and climate modeling tools enable farmers to anticipate adverse weather events and adapt their practices accordingly. For example, machine learning algorithms can analyze historical weather data to forecast optimal planting and harvesting times, thus reducing crop losses associated with extreme weather patterns.

The integration of AI into agriculture also raises important ethical considerations. As agricultural technologies evolve, issues such as data privacy, the accessibility of advanced tools among smallholder farmers, and the potential for job displacement within the agricultural workforce must be addressed. Policymakers and industry stakeholders must work together to develop frameworks that ensure equitable access to AI resources while promoting sustainable practices that benefit both farmers and the environment.

In conclusion, the convergence of AI and agriculture presents a significant opportunity to reshape the way food is produced and delivered. By harnessing the power of AI, the agricultural sector can enhance productivity, bolster climate resilience, and contribute to global food security in an era marked by unprecedented challenges and uncertainties. As research and development in this field continue to evolve, it is imperative that stakeholders remain vigilant in addressing the ethical and practical implications of these transformative technologies to ensure a sustainable and equitable agricultural future.

Irrigation system

The rapid expansion of artificial intelligence (AI) technologies within the agricultural sector has the potential to significantly enhance irrigation systems, thereby improving water management and crop productivity. Effective irrigation practices are critical in ensuring optimal crop growth and minimizing water wastage, especially in a country like Iran where water scarcity poses substantial challenges to agricultural sustainability.



AI-driven irrigation solutions can optimize water usage through the integration of real-time data, predictive modeling, and automated control systems. The burgeoning agri-tech sector is poised to leverage AI in transformative ways. Intelligent irrigation systems can utilize data from soil moisture sensors, weather forecasts, and crop health monitoring to determine the precise irrigation needs of crops. Machine learning algorithms can analyze historical and current data to establish patterns in water requirements, allowing for timely irrigation that aligns with the unique needs of specific crops and climatic conditions.

Moreover, the application of AI in irrigation extends to the development of smart irrigation systems, which can be equipped with IoT (Internet of Things) devices. These devices facilitate remote

monitoring and control of irrigation practices, enabling farmers to make informed decisions even from distant locations. For instance, mobile applications can provide farmers with alerts about when to irrigate based on real-time soil moisture levels, thus promoting more efficient water usage.

The financial investments flowing into the agri-tech sector, as evidenced by the significant fundraising activities of iran agri-food tech startups, illustrate a growing recognition of the role that Innovative technologies can play in enhancing agricultural individual startups are increasingly recognizing the opportunities presented by AIparticularly powered solutions. in irrigation management. The estimated growth trajectory of the global AI applications in agriculture market—from \$852.2 million in 2019 to an anticipated valuation of almost \$8.38 billion by 2030—underscores the scalability and potential impact of these technologies. This presents an opportunity for startups to innovate and provide solutions that address the critical needs of the agricultural sector. In conclusion, the integration of artificial intelligence into irrigation systems within the agricultural landscape represents a promising shift toward enhancing productivity and sustainability. fostering technological By advancements and encouraging private sector investment in agri-tech, Iran can bolster its agricultural output and ensure a more resilient food system. Emphasizing the importance of technology in agriculture also aligns with broader goals of economic growth and social empowerment, ultimately contributing to the well-being of farmers and the nation as a whole. The ongoing developments in this domain will be critical to navigating the challenges of food security and resource management in the 21st century.



History of Artificial intelligence

The Church-Turing thesis provides a foundational framework for understanding the capabilities and

limitations of computational systems in simulating intelligent behavior. At its core, the thesis posits that any function that can be computed by an algorithm can be computed by a Turing machine. This conceptualization of computation has profound implications for the development of artificial intelligence, framing the pursuit of creating machines that exhibit reasoning capabilities as an extension of formal logic and mathematics.

Historically, the evolution of computational theory has roots in early philosophical inquiries into the nature of certainty and deduction. Ancient philosophers sought to delineate valid forms of argumentation, laying the groundwork for the logical systems that would eventually inform modern computation. The writings of Aristotle, with their emphasis on syllogistic reasoning, and the work of later philosophers and logicians contributed to a body of knowledge that would culminate in the formalization of logical principles.

Alan Turing's pioneering work in the mid-20th century further propelled the study of artificial intelligence by introducing the concept of the Turing machine as a theoretical construct for understanding computation. The Turing machine operates under a set of simple rules, manipulating symbols on a tape according to defined operations. Turing's analysis of the machine's capabilities demonstrated that it could perform any calculation that could be articulated as a procedure, thereby establishing profound connection between logic, computation, and the potential for machines to replicate human-like reasoning.

As the field of artificial intelligence has matured, it has come to encompass not only formal reasoning but also various forms of learning and adaptation. The advent of machine learning techniques—such as neural networks and reinforcement learning—has enabled artificial systems to develop complex behaviors that closely mirror aspects of human cognition. These advancements raise pertinent ethical questions not unlike those depicted in early fictional representations of intelligent beings. The narratives explored in Mary Shelley's "Frankenstein" and Karel Čapek's "R.U.R." serve as cautionary illustrating the unforeseen consequences that may endowed arise from creating entities autonomous reasoning capabilities.

The ethical discourse surrounding AI includes concerns regarding accountability, transparency, and the moral implications of granting intelligent systems agency. As machines increasingly partake in decisionmaking processes across diverse fields—ranging from healthcare to criminal justice—the need for ethical frameworks that govern their development and deployment becomes imperative. Questions surrounding the rights of artificial intelligences, the implications of their decisions, and the potential for inherent biases in algorithmic reasoning echo the existential dilemmas posed in earlier literary explorations.

In summary, the intersection of computational theory, artificial intelligence, considerations reveals the complexity of creating and integrating intelligent systems into society. As we stand at the precipice of a new era dominated by AI, it is crucial to reflect upon the historical narratives and philosophical inquiries that have shaped our understanding of intelligence. By critically engaging with both the theoretical foundations and potential ramifications of artificial beings, we can better navigate the ethical landscape of emerging technologies, ensuring that their trajectory benefits humanity in ways that are just, equitable, and sustainable.

Development of agriculture system



The evolution of robotics in agriculture is a fascinating journey, reflecting broader technological advancements that have influenced various sectors. The roots of agricultural automation can indeed be traced back to the 1920s when preliminary research into automated vehicle steering began to emerge. This pioneering work laid the groundwork for subsequent innovations in agricultural machinery, setting the stage for the advent of self-driving vehicles tailored for farming applications in the subsequent decades.

During the 1950s and 1960s, significant strides were made in developing autonomous agricultural vehicles. However, these early models were limited by their dependence on cable systems for guidance, indicating that while progress had been made, the technology was not fully autonomous. The reliance on external guiding systems underscored the nascent stage of robotics in agriculture, highlighting the need for more refined technological interventions that could facilitate genuine autonomy.

The 1980s heralded a breakthrough in the agricultural robotics sector, coinciding with the rapid advancement of computer technology. The development of computer processing capabilities played a pivotal role in enabling machine vision—a critical component that allows robots to interpret visual information from their environment. With the integration of sophisticated sensors and cameras, robots could now navigate complex agricultural landscapes, making decisions based on real-time data analysis rather than external guiding systems.

Machine vision technology empowered agricultural robots to perform a variety of tasks with increased precision and efficiency. For instance, robots equipped with image recognition could identify ripe fruits, assess crop health by analyzing leaf color and texture, and even detect pest infestations. These capabilities marked a significant departure from traditional farming practices, allowing for more targeted interventions that improve yield and reduce resource wastage.

The convergence of robotics, machine vision, and data analytics in agriculture has continued to flourish into the 21st century, as advancements in artificial intelligence further augment the capabilities of agricultural robots. Modern systems are now able not only to perform repetitive tasks—such as planting, watering, and harvesting—but also to learn from their environments, adapt to changing conditions, and make predictive analyses that contribute to overall farm management.

In recent years, the emergence of collaborative robots, or cobots, has also transformed the agricultural landscape by enabling human-robot cooperation. These robots can be designed to assist human workers, enhancing productivity and minimizing physical strain while performing laborintensive tasks. The shift towards automation in agriculture also raises important considerations regarding labor dynamics, as the coexistence of human workers and automated systems necessitates

discussions surrounding workforce re-skilling and adaptation to changing job requirements.

In conclusion, the historical trajectory of robotics in agriculture illustrates a clear evolution from rudimentary automations relying on external controls to sophisticated autonomous systems capable of complex tasks and decision-making. As technology continues to advance, it is essential to consider not only the efficiencies that robotics can bring but also the broader impacts on the agricultural workforce, food production sustainability, and environmental stewardship. ongoing development The agricultural robotics has the potential to shape the future of farming, presenting opportunities for increased productivity while addressing the pressing challenges posed by climate change, population growth, and resource management.

Fucture agriculture system

The use of artificial intelligence (AI) in agriculture undeniably represents a promising avenue for addressing some of the challenges posed by climate change; however, it is essential to recognize that AI alone cannot serve as a comprehensive solution. While adaptive technologies such as AI can indeed enhance agricultural resilience, optimize resource management, and improve crop yields, they must be part of a broader strategy that incorporates sweeping systemic measures to ensure food security in a rapidly changing climate.

Firstly, it is imperative to acknowledge that the impacts of climate change extend beyond localized agricultural practices. Rising global temperatures, shifting precipitation patterns, and increasingly erratic weather events threaten the stability of food systems worldwide. Consequently, strategies aimed at stabilizing global food access must encompass a range of interventions, including sustainable agricultural practices, diversified cropping systems, and enhancement of food distribution networks. These broader measures require not only technological innovation but also policy reform, investment in infrastructure, and an emphasis on sustainable land management practices.

Furthermore, integrating AI into agricultural sectors must be approached with a critical evaluation of the potential costs associated with implementation. High initial investments in financial technology can pose barriers smallholder farmers, particularly in developing countries where access to resources and technical expertise may be limited. Therefore, international collaboration is necessary to alleviate these economic barriers and ensure equitable access to AI technologies. Global leaders should prioritize investment strategies that support capacity-building initiatives and provide financial assistance to vulnerable farming communities, enabling them to leverage AI's benefits without exacerbating existing inequalities.

Additionally, the role of legal institutions cannot be overlooked in shaping the responsible deployment of AI in agriculture. As AI technologies continuously evolve, regulatory frameworks must be updated to address issues such as data privacy, intellectual property rights, and accountability for decisions made by AI systems. The development of clear and equitable legal guidelines not only fosters ethical AI usage but also ensures transparency and builds trust among stakeholders, which is vital for facilitating the adoption of these technologies in agricultural practices.

Moreover, the environmental consequences of AI data processing warrant careful consideration. The infrastructure required to support AI systems, including data centers and computational resources, can have a considerable carbon footprint and pose additional environmental challenges. As such, it is critical to explore sustainable energy sources and efficient computing methods that minimize the ecological impact of AI deployment in agriculture.

While AI offers valuable tools for enhancing agricultural adaptability in the face of climate change, it should not be viewed in isolation. A comprehensive strategy that incorporates multifaceted actions—ranging from sustainable agricultural practices to equitable investment frameworks-is essential for securing global food systems. As nations invest in AI technologies for agriculture, they must also prioritize collaborative efforts aimed at promoting food security, addressing disparities. socio-economic and ensuring environmental stewardship. Ultimately, by working together to confront the challenges posed by climate change, global leaders can foster resilient agricultural systems capable of sustaining future generations.

4-Conclusion

The agriculture and food industries are essential human sustenance and development, characterized by complex interdependencies among stakeholders across four main clusters: preproduction, production, processing, and distribution. To address challenges such as climate change, population growth, and resource depletion, the agricultural supply chain is crucial. Key advancements include the automation of farm machinery, which enhances efficiency and optimizes farming practices through sophisticated sensors. Additionally, real-time data collection enables precision agriculture, improving productivity and sustainability by minimizing resource waste.

Artificial intelligence (AI) and machine learning (ML) are transformative tools across the supply chain. In preproduction, AI aids in optimal planting decisions, while ML enhances crop health during production through data analysis. In processing and

leveraging digital technologies in distribution, AI improves food traceability, ensuring safety and transparency throughout the supply chain. The growing adoption of AI and ML reflects farmers' recognition of data-driven approaches for efficiency and resilience. As these technologies evolve, they hold significant potential for improving food security and promoting sustainable agricultural practices. Collaboration among stakeholders is essential to advance research, investment, and education on these technologies, maximizing their positive impact on the agriculture and food industries.

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