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SMART AGRICULTURE: THE ROLE OF ARTIFICIAL INTELLIGENCE IN IMPROVING CROP PRODUCTION AND ENVIRONMENTAL SUSTAINABILITY

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Abstract: *The increasing integration of digital technologies into agricultural activities is creating new opportunities to address the complex relationship between food production and environmental protection. Among these innovations, Artificial Intelligence (AI) plays an increasingly important role in supporting agricultural decision-making and improving the management of natural resources. This research investigates how AI applications can contribute to crop productivity while encouraging farming practices that are compatible with long-term environmental sustainability. Attention is given to the use of intelligent systems for identifying variations in soil quality, evaluating plant health, anticipating weather-related disturbances, and determining appropriate agricultural interventions. Technologies such as machine learning, automated image recognition, and data-driven monitoring platforms allow agricultural producers to better understand field conditions and respond to changes throughout the growing season. Moreover, the combination of AI algorithms with connected sensors and satellite observations provides valuable information for adjusting irrigation schedules, managing nutrient requirements, and preventing crop losses. Beyond increasing production efficiency, these developments offer opportunities to limit unnecessary chemical treatments, conserve freshwater resources, and reduce the ecological pressures generated by intensive cultivation. Nevertheless, the transition toward AI-supported agriculture raises important questions concerning technological affordability, farmers' digital competencies, infrastructure availability, and the reliability of automated recommendations.*

Introduction

Agricultural production is undergoing a profound transformation as digital technologies become increasingly integrated into farming activities. The growing demand for food, combined with climate change, soil degradation, water scarcity, and increasing pressure on natural resources, has created the need for innovative agricultural management strategies capable of improving crop productivity while maintaining environmental sustainability. Within this context, smart agriculture represents an important development pathway that combines technological innovation, data-driven decision-making, and responsible resource management. Smart agriculture refers to the application of advanced digital technologies to agricultural production systems in order to improve monitoring, forecasting, operational efficiency, and decision-making. Among these technologies, Artificial Intelligence (AI) has gained particular importance because of its capacity to analyze complex datasets, identify relationships between environmental variables, and generate recommendations adapted to specific agricultural conditions. Traditional agricultural management frequently relies on farmers' experience, periodic field observations, and generalized interventions applied across agricultural areas. Although practical knowledge remains essential, these approaches may not fully capture the spatial and temporal variability of soil characteristics, crop development, nutrient availability, and environmental conditions.

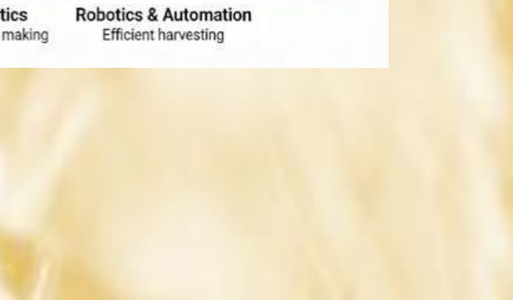




Material and method

The present research adopts a qualitative, descriptive, and comparative analytical approach based on the examination of scientific literature and secondary information concerning Artificial Intelligence, smart agriculture, crop production, and environmental sustainability. The methodological framework focuses on identifying the principal applications of AI in crop management and evaluating their potential contribution to agricultural productivity, resource-use efficiency, and environmental protection. The research is organized around six analytical dimensions: soil-quality monitoring, crop-health assessment, weather-related risk prediction, intelligent irrigation management, nutrient optimization, and the technological and socioeconomic conditions influencing AI adoption. The analytical framework is designed to draw upon scientific publications, agricultural technology studies, and institutional reports concerning digital agriculture and sustainable crop production. Relevant institutional sources may include materials published by the Food and Agriculture Organization of the United Nations (FAO), the European Commission, and agricultural research organizations.
The assessment considers four principal criteria: potential improvements in crop management, resource-use efficiency, environmental performance, and practical accessibility for agricultural producers. A thematic synthesis is proposed to compare the functions, potential benefits, and limitations of different AI applications. Particular attention is given to the relationship between improved agricultural decision-making and environmental sustainability.





Results and discussions

The analysis identifies several important areas in which Artificial Intelligence can support crop production and environmental sustainability. The principal themes emerging from the analytical framework concern the identification of soil variability, monitoring of plant health, prediction of environmental disturbances, optimization of water and nutrient management, and the integration of technological recommendations into practical agricultural decision-making. The findings suggest that the potential contribution of AI depends on its ability to transform agricultural data into accurate, timely, and contextually appropriate management recommendations. The effectiveness of AI-supported agriculture depends on the suitability of technological applications for specific crops, soil conditions, climatic environments, and farm management systems. For example, intelligent irrigation may improve water-use efficiency when reliable soil moisture measurements and appropriate irrigation infrastructure are available. Similarly, AI-supported nutrient management may reduce unnecessary fertilizer consumption when recommendations are based on representative soil information and validated agronomic models. The integration of crop monitoring with weather prediction can also improve the timing of agricultural operations and support more responsive management strategies. From an economic perspective, technological adoption requires consideration of investment costs, maintenance requirements, expected benefits, and farmers' capacity to utilize digital information. The development of accessible digital platforms, cooperative monitoring services, and agricultural training programmes may improve opportunities for smaller producers. Institutional cooperation is equally important. Universities, agricultural research organizations, technology developers, public authorities, and farming communities can contribute to the development and validation of reliable AI applications. Environmental indicators should also be incorporated into the evaluation of smart agricultural technologies. Measures such as water-use efficiency, nutrient-use efficiency, pesticide application intensity, soil quality, and crop productivity can provide useful information regarding the relationship between agricultural performance and environmental sustainability.





Conclusions

The present research highlights the potential contribution of Artificial Intelligence to improving crop production and promoting environmental sustainability through intelligent monitoring, predictive analytics, and data-driven agricultural management. The analysis identifies soil-quality monitoring, crop-health assessment, weather-risk prediction, irrigation optimization, and nutrient management as important areas in which AI technologies can support agricultural decision-making. AI-supported soil monitoring can contribute to identifying spatial variations in agricultural conditions and improving the management of soil resources. Automated crop-health assessment offers opportunities for earlier identification of plant stress and more targeted agricultural interventions. Weather-related predictive models can support agricultural planning and improve preparedness for environmental disturbances, particularly under increasingly variable climatic conditions. Intelligent irrigation systems may contribute to more efficient water management by integrating soil moisture information, weather forecasts, and crop water requirements. Similarly, AI-supported nutrient management can facilitate more accurate fertilizer recommendations and potentially reduce unnecessary agricultural inputs. The integration of machine learning algorithms with connected sensors, satellite observations, and digital monitoring platforms provides opportunities for developing more responsive and information-based agricultural production systems. Nevertheless, the successful implementation of AI technologies depends on technological affordability, digital infrastructure, data reliability, farmers' competencies, and the availability of appropriate technical support.





