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SMART AGRICULTURE IN THE CONTEXT OF DIGITALIZATION AND GREEN TRANSITION

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Abstract: Smart agriculture, driven by the growing trend of digitization, serves as a crucial element in the green transition towards sustainable food systems. This paper investigates how the integration of contemporary digital technologies – including the Internet of Things (IoT), artificial intelligence (AI), drones, satellite monitoring, and blockchain – facilitates the shift from conventional production models to practices that are environmentally, economically, and socially sustainable. By reviewing pertinent literature, the primary advantages of digitized agriculture are highlighted: enhanced resource efficiency, decreased greenhouse gas emissions, increased yields, and improved access to green finance and markets. The paper also underscores the implementation challenges faced in rural regions, such as elevated costs, digital illiteracy, insufficient infrastructure, and data security concerns. In conclusion, it is asserted that smart agriculture, as a product of digitization and the green transition, holds the promise to transform the agricultural sector's role in sustainable development, contingent upon the backing of suitable policies, investments, and educational initiatives.

Keywords: *Smart agriculture, digital technologies, green transition, IoT, AI, sustainable agriculture.*

INTRODUCTION

Contemporary agriculture encounters several global challenges, including climate change, the reduction of arable land, an increasing demand for food, and the necessity to preserve biodiversity (UNEP, 2011; UN, 2015). Traditional agricultural models frequently result in the overexploitation of resources, pollution of soil and water, and heightened greenhouse gas emissions (OECD, 2019). In this scenario, the green transition in agriculture signifies a shift towards sustainable and environmentally responsible practices that facilitate productive yet ecologically acceptable food production (European Environment Agency, 2021).

Digitization emerges as a pivotal factor in this transition, as it allows for the incorporation of innovative technologies that enhance the precise management of resources, streamline production processes, and mitigate adverse environmental effects (Wolfert et al., 2017). Smart Farming employs a blend of sensors, drones, GPS technology, artificial intelligence, and software solutions to assess the status of crops, soil, and livestock, thereby enabling the efficient use of water, fertilizers, and pesticides (Kouhizadeh & Sarkis, 2018; Zhang et al., 2020; Nezamova and Olentsova, 2022).

Beyond its environmental advantages, the digital transformation of agriculture also plays a significant role in achieving the economic and social objectives of sustainable development. Enhanced production efficiency leads to lower costs and higher yields, while the emergence of digital platforms and analytical tools allows farmers to tap into green finance and market opportunities (Wolfert et al., 2017; UNEP, 2011). The digitization of agriculture has the potential to mitigate social inequalities by broadening access to markets, financial services, and educational resources. For instance, digital technologies can facilitate market access for small-scale farmers, thereby decreasing transaction costs and alleviating information asymmetries (Petrović et al., 2022).

The objective of this paper is to examine the use of digital technologies in smart agriculture, highlighting their ecological, economic, and social advantages, along with the obstacles encountered during their implementation in the green transition process. Particular emphasis is placed on linking digitization to the principles of sustainable development and the circular economy (UN, 2015; OECD, 2019).

METHODOLOGY

Smart Farming uses the integration of sensors, drones, GPS technology, AI and software solutions to monitor the condition of crops and animals. Methodologically, the analysis in this paper is based on a literature study and a synthesis of previous research that connects digitization, agriculture and the green economy.

Special attention is paid to:

1. Optimization of resources and energy efficiency
2. Reducing emissions and environmental impact
3. Integration of circular economic principles

Digital technologies in smart agriculture

Internet of Things (IoT) and sensors

IoT devices enable monitoring of microclimate, soil moisture, crop conditions and water supplies. Precise irrigation and fertilizer application reduce the unnecessary consumption of resources and the emission of harmful gases (OECD, 2019). The use of sensors and smart irrigation systems enables real-time data collection, enabling farmers to make informed decisions and optimize water and fertilizer use (Zhang et al., 2020). In addition, the application of IoT technologies in agriculture can contribute to the reduction of greenhouse gas emissions through reduced use of machinery and more rational use of inputs (FAO, 2021; Bacco et al., 2019). IoT systems, when combined with artificial intelligence, enable predictive analysis and automatic resource management, further increasing the efficiency and sustainability of agricultural production (Wolfert et al., 2017).

Artificial intelligence and data analytics

The advancement of artificial intelligence (AI) and big data analytics (Big Data) signifies a crucial progression towards digitization and enhancement of sustainable agricultural production. AI models are employed to forecast the ideal sowing and harvesting times, in addition to identifying and diagnosing diseases and pests affecting crops, which facilitates prompt preventive actions and minimizes losses (Wolfert et al., 2017). By utilizing deep learning techniques, it becomes feasible to automatically assess images captured by satellites, drones, or smart cameras to detect stress factors impacting plant health (Kamilaris & Prenafeta-Boldú, 2018). These systems aid in optimizing the management of resources such as water and fertilizers, thereby boosting efficiency and lessening the ecological footprint of production.

Through the integration of AI with data from IoT sensors, weather models, and market analysis, decision-making at the farm level can be enhanced via automated recommendations and predictive models (Liakos et al., 2018). Such systems facilitate accurate production planning, prompt responses to climate change, and a decrease in reliance on chemical agents (Shamshiri et al., 2018). In this regard, AI serves as a pivotal technology for realizing the objectives of smart and sustainable agriculture..

Drones and satellite surveillance in precision agriculture

The utilization of unmanned aerial vehicles (drones) and satellite surveillance is becoming increasingly significant in the realm of precision agriculture, which aims for more efficient, sustainable, and informed resource management. These technologies facilitate detailed and timely monitoring of extensive agricultural regions, the identification of stress factors such as diseases, drought, water saturation, and nutrient deficiencies, as well as the mapping of soil variability (European Environment Agency [EEA], 2021).

Drones that are outfitted with multispectral and thermal cameras deliver high-resolution real-time data, enabling farmers to swiftly address identified issues, thereby minimizing pesticide and water consumption through targeted interventions on only the affected sections of fields (Tsouros et al., 2019). Conversely, satellite systems like the Copernicus Sentinel missions provide continuous surveillance of vast areas throughout the entire growing season, thus supporting long-term planning and enhancement of crop management strategies (Misra et al., 2020).

The implementation of these technologies not only aids in boosting yields and economic viability but also significantly mitigates adverse environmental impacts through the precise application of agricultural practices and the judicious use of resources.

Blockchain technology in agriculture

Blockchain technology constitutes a decentralized digital ledger that facilitates secure, unalterable, and transparent storage and exchange of data, which holds significant relevance in contemporary agricultural supply chains. The adoption of a blockchain framework allows for comprehensive traceability of products from producers to end consumers, thereby enhancing consumer confidence and verifying the sustainable origins of agricultural goods (Kouhizadeh & Sarkis, 2018).

Through the utilization of smart contracts, blockchain fosters the automation of transactions among various participants in the supply chain, such as farmers, distributors, processors, and retailers. This mechanism not only diminishes administrative expenses but also mitigates fraud and accelerates the movement of goods and information (Zhang et al., 2020). Furthermore, blockchain is increasingly recognized as a foundational technology for trading carbon credits in sustainable agriculture, facilitating real-time validation of CO2 emission and sequestration data at the farm level (Tripoli & Schmidhuber, 2018).

The implementation of this technology can also enhance the inclusion of small-scale producers in global value chains, as it provides a transparent record of adherence to quality standards, eliminating the necessity for intermediaries or central authorities (Tian, 2016). Over the long term, blockchain has the potential to significantly transform the efficiency, safety, and sustainability of agricultural markets.

Benefits of smart agriculture

Smart agriculture, based on digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), drones, blockchain and satellite surveillance, brings multiple benefits in order to achieve sustainable, efficient and inclusive agricultural production. These benefits can be classified into three main categories: environmental, economic and social.

1. Environmental benefits

One of the key goals of smart agriculture is to reduce the negative impact on the environment. The use of sensors and systems for precise irrigation enables the optimization of water consumption, while the precise application of pesticides and fertilizers reduces soil and groundwater pollution (FAO, 2021). Automation and digital monitoring reduce the need for multiple machine passes through the fields, which directly affects the reduction of carbon dioxide emissions (OECD, 2019). In addition, by applying AI algorithms, it is possible to effectively detect plant diseases at an early stage, thus minimizing the need for chemical treatments (Kamilaris & Prenafeta-Boldú, 2018).

2. Economic benefits

Digitization in agriculture brings significant economic advantages. Accurate management of resources and timely application of agrotechnical measures result in higher yields and reduced operating costs (Wolfert et al., 2017). By using data analytics and predictive models, farmers can make informed decisions that increase profitability. Also, verification of sustainability through blockchain technology enables access to markets with higher standards and easier access to green finance and subsidies (Tripoli & Schmidhuber, 2018).

3. Social benefits

Smart agriculture also contributes to the improvement of social capital in rural areas. The training and involvement of farmers in digital technologies enables their integration into modern economic flows and increases competitiveness in the market (Lioutas et al., 2019). Also, the development of digital platforms and services opens up space for new green jobs in sectors such as data analysis, IoT system maintenance, digital marketing and e-commerce. In a broader sense, smart agriculture encourages local development, education and strengthening the resilience of communities to climate and market changes.

Challenges of Implementing Smart Agriculture

While smart agriculture presents numerous advantages for the sustainability, efficiency, and resilience of food systems, its implementation encounters several obstacles that impede broader adoption, particularly in developing nations and rural regions.

1. High Initial Costs of Technology and Infrastructure

A primary challenge pertains to the substantial initial expenses associated with the introduction of digital technologies. This includes the acquisition of IoT devices, drones, sensors, computing equipment, and software platforms, alongside investments in internet connectivity and energy infrastructure. Such financial commitments are often beyond the reach of many small and medium-sized agricultural producers without governmental assistance or access to favorable financial options (Klerkx et al., 2019).

2. Digital Illiteracy and the Need to Educate Farmers

The deficiency of digital skills among farmers, particularly among the elderly and those residing in remote locations, significantly obstructs the effective utilization of available technologies. Education, training, and technical support are essential for enhancing acceptance and ensuring the successful integration of digital tools into daily agricultural practices (Rose et al., 2021).

3. Data Security and Privacy Protection

The utilization of digital tools necessitates the collection of extensive data regarding land, crops, yields, and producer activities. Concerns surrounding data security, privacy, and information ownership are becoming increasingly critical, as there is currently no universally recognized regulatory framework to safeguard the interests of farmers within the digital landscape (Bronson, 2018).

4. Uneven Availability of Digital Infrastructure in Rural Areas

Access to broadband internet and mobile networks remains restricted in numerous rural and remote areas, which directly impacts the feasibility of implementing digital solutions in agriculture. The digital divide between urban and rural communities exacerbates economic and technological disparities (OECD, 2021).

CONCLUSION

Smart agriculture represents a fundamental component of the green transition and the evolution of contemporary food systems. By merging digital technologies with sustainable development principles, it facilitates more precise, efficient, and responsible management of natural resources, which positively influences economic profitability, ecological balance, and the social inclusiveness of rural communities. When implemented effectively, smart agriculture optimizes the use of water, fertilizers, and pesticides, reduces greenhouse gas emissions, enhances agricultural yields, and provides easier access to markets that demand traceability, quality, and sustainability in production.

Nevertheless, to fully harness these potentials, it is essential to establish comprehensive public policies that foster investments in digital infrastructure, enhance digital literacy among farmers, and ensure access to financial mechanisms for small and medium-sized producers. A significant challenge lies in ensuring uniform access to technology to prevent the exacerbation of existing socio-economic disparities between developed and underdeveloped regions.

The future of smart agriculture will hinge on the capacity of various stakeholders including institutions, researchers, the private sector, and farmers to collaborate in creating open, accessible, and sustainable solutions. Only through such an integrative approach can we guarantee that the digital transformation of agriculture becomes a shared opportunity rather than a privilege for a select few, serving as a catalyst for inclusive and green growth across society.

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REFERENCES

1. Bacco, M., Bertoncini, M., Gotta, A., & Zoppi, M. (2019). Smart farming: Opportunities, challenges and technology enablers. IoT Vertical and Topical Summit on Agriculture – Tuscany 2019, IEEE. https://doi.org/10.1109/IoT-Tuscany.2019.101
2. Bronson, K. (2018). Smart farming: Including rights holders for responsible agricultural innovation. Technology Innovation Management Review, 8(2), 7–14. https://doi.org/10.22215/timreview/1135
3. European Environment Agency (2021). Digitalisation and the environment. EEA Report No 3/2021.
4. European Environment Agency. (2021). Precision agriculture and the future of farming in Europe. https://www.eea.europa.eu/
5. FAO. (2021). Digital agriculture: Farmers in the driver's seat. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/cb3170en/cb3170en.pdf
6. IEA (2020). Tracking Transport 2020. International Energy Agency.
7. Kamilaris, A., & Prenafeta-Boldú, F. X. (2018). Deep learning in agriculture: A survey. Computers and Electronics in Agriculture, 147, 70–90. https://doi.org/10.1016/j.compag.2018.02.016
8. Klerkx, L., Jakku, E., & Labarthe, P. (2019). A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. NJAS - Wageningen Journal of Life Sciences, 90–91, 100315. https://doi.org/10.1016/j.njas.2019.100315

9. Kouhizadeh, M., & Sarkis, J. (2018). Blockchain practices, potentials, and perspectives in greening supply chains. Sustainability, 10(10), 3652. https://doi.org/10.3390/su10103652
10. Liakos, K. G., Busato, P., Moshou, D., Pearson, S., & Bochtis, D. (2018). Machine learning in agriculture: A review. Sensors, 18(8), 2674. https://doi.org/10.3390/s18082674
11. Lioutas, E. D., Charatsari, C., & De Rosa, M. (2019). Digital technologies in agriculture: Promises, pitfalls and prospects. Technology in Society, 58, 101994. https://doi.org/10.1016/j.techsoc.2019.101994
12. Misra, D., Manjunath, K. R., Srivastava, R., & Parihar, J. S. (2020). Satellite remote sensing for precision agriculture: Current status and future perspective in India. Journal of the Indian Society of Remote Sensing, 48(6), 829–845. https://doi.org/10.1007/s12524-020-01101-4
13. Nezamova, A., and Olentsova, J.A. (2022). The main trends of digitalization in agriculture *IOP Conf. Ser.: Earth Environ. Sci.* 981 032018
14. OECD (2019). Digitalisation and the environment: Opportunities and challenges. OECD Publishing.
15. OECD. (2019). Digital Opportunities for Better Agricultural Policies. Organisation for Economic Co-operation and Development. https://doi.org/10.1787/571a0812-en
16. OECD. (2021). Broadband policies for Latin America and the Caribbean: A digital economy toolkit. Organisation for Economic Co-operation and Development. https://doi.org/10.1787/9a9479b1-en
17. Petrović, D. Č., Stanimirović, P. Z., & Vratonjić Gligorijević, A. M. (2022). Značaj projekata digitalne transformacije u poljoprivredi i izazovi njihove ocene opravdanosti. Tehnika, 77(6), 767-773. https://doi.org/10.5937/tehnika2206767P
18. Rose, D. C., Sutherland, W. J., Barnes, A. P., Borthwick, F., Ffoulkes, C., Hall, C., ... & Twining, S. (2021). The role of stakeholder networks in smart farming adoption: Implications for inclusive innovation. Agricultural Systems, 190, 103107. https://doi.org/10.1016/j.agsy.2021.103107
19. Shamshiri, R. R., Kalantari, F., Ting, K. C., Thorp, K. R., Hameed, I. A., Weltzien, C., & Shad, Z. M. (2018). Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. International Journal of Agricultural and Biological Engineering, 11(1), 1–22. https://doi.org/10.25165/j.ijabe.20181101.3210
20. Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. 13th International Conference on Service Systems and Service Management (ICSSSM), 1–6. https://doi.org/10.1109/ICSSSM.2016.7538424
21. Tripoli, M., & Schmidhuber, J. (2018). Emerging opportunities for the application of blockchain in the agri-food industry. Food and Agriculture Organization of the United Nations (FAO) and International Centre for Trade and Sustainable Development (ICTSD). https://www.fao.org/3/CA1335EN/ca1335en.pdf
22. Tsouros, D. C., Bibi, S., & Sarigiannidis, P. G. (2019). A review on UAV-based applications for precision agriculture. Information, 10(11), 349. https://doi.org/10.3390/info10110349

23. UN (2015). Transforming our world: the 2030 Agenda for Sustainable Development. United Nations.
24. UNEP (2011). Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. United Nations Environment Programme.
25. Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big Data in Smart Farming – A review. Agricultural Systems, 153, 69–80.
26. Zhang, Y., Wu, L., & Yin, X. (2020). Application of Internet of Things Technology in Precision Agriculture. Journal of Physics: Conference Series, 1651(1), 012092. https://doi.org/10.1088/1742-6596/1651/1/012092
27. Zhang, Y., Xue, C., & Liu, Y. (2020). Security and privacy on blockchain. ACM Computing Surveys (CSUR), 52(3), 1–34. https://doi.org/10.1145/3316481