METHODS OF DIGITALIZATION OF AGRICULTURE PRACTICED IN ROMANIA

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Abstract

In Romania, the agricultural sector is considered one of the most important sectors of the national economy, which has a strategic role in ensuring food security. In these conditions, along with the trend of population growth, there is also an increase in demand for agri-food products, and the influence of climate change on agricultural production requires the need to move from traditional agricultural methods to precision ones. This study aims to contribute to the development of research on this topic by investigating and presenting the most important and well-known ways of digitizing agriculture practiced in Romania.

Key words: agriculture, digitization, digitization methods.

Discussions regarding the digitalization of agriculture appeared for the first time since 1990. The first paper indexed in WoS on the subject of "digitalization in agriculture" was published in 1991, being developed by Everitt *et al*, (1991) which presented the importance of using aerial video systems for agricultural assessment. The findings of the study showed that aerial video systems used in agriculture are proposed as an alternative for providing real-time information on natural resources in agriculture.

The transformation of agriculture globally is being accelerated by the adoption of digital technologies, which are essential not only to meet the increasing food demands of a growing population, but also to meet the challenges of climate change, responsible use of resources and optimization economic efficiency. In Romania, the digitization of agriculture has become a strategic priority in the modernization of this crucial sector. Romanian farmers, from small owners to large agricultural companies, enthusiastically adopt the solutions offered by precision agriculture, which not only monitor crops and soil in real time, but also allow more effective interventions, customized to the needs of each farm.

Emerging technologies such as soil and crop sensors, satellite remote sensing, the use of drones for monitoring and enforcement, as well as the integration of IoT and AI systems into agricultural processes, not only increase productivity and reduce losses, but also contribute to increased sustainability in agriculture. The implementation of these technologies has begun to redefine farmers' interaction with supply chains and the market, giving them expanded control over the entire production and distribution process.

Digitization in agriculture represents not only a technological advance, but also a paradigm shift, transforming the role of farmers within the value chain and contributing to the development of a more resilient agriculture adapted to the challenges of the future. As Romania continues to adopt these innovations, it is essential to focus not only on implementing the technologies, but also on training and educating farmers to enable them to effectively use these new tools and realize their full potential.

Thus, the digitization of agriculture not only promises to improve yields and efficiency, but also plays a crucial role in achieving sustainable development goals, while ensuring long-term food security. The transition to digitized agriculture, however, requires close collaboration between government, the private sector and the scientific community to create an enabling environment for innovation and the widespread adoption of digital technologies in agriculture.

With the help of agricultural digitization methods, a farmer can simultaneously communicate with several robotic devices, sending them specific instructions, thus synchronizing the work between them. Such activities in the agricultural sector help to save time and achieve high productivity (Atkočiūnienė & Papšienė, 2023).

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Simo *et al*, (2022) presents the term digitization of agriculture referring to the concept of management, centered on industrial agriculture. Digital agriculture uses state-of-the-art technologies such as: Big data, Cloud and Internet of Things to monitor, automate and evaluate agricultural processes, therefore digital agriculture can be considered a management tool.

On the other hand, Meng *et al*, (2024) is of the opinion that the digitization of agriculture serves as an essential means of introducing innovative agricultural practices and achieving sustainable agricultural development. The authors also argue that although the digitization of agriculture has received increased attention, its development has been unbalanced. The gaps in the digitization process in agriculture represent great challenges in the development of sustainable agriculture. This is presented in the European Green Deal, in which the use of digital technology in agriculture (sensors, satellites, artificial intelligence, etc.) has been strengthened to develop sustainable agriculture and control the impact of climate change. Among the current challenges facing the agricultural sector, climate change is among the most important. (Pătărlăgeanu *et al*, 2024).

At the same time, Meghișan-Toma *et al*, (2020) consider that digitization is one of the tools that can make a significant contribution to the optimization of agricultural processes, from a sustainable perspective.

Although this aspect is obvious and already demonstrated, a large part of these new technologies and digital systems are pushed to farmers and are not developed following their requests. This situation is found among Romanian farmers in a very high percentage, but it is not an isolated situation, in a recent study Gaber K. *et al*, (2024) draw attention to the need to take into account the perception of stakeholders for a better adoption of new technologies (Gaber K. *et al*, 2024).

The impact of digitization on the development of agriculture is also analyzed in the specialized literature. A study by Rodino *et al*, (2023) showed that the digitization of agriculture has a significant impact on human and material resources, contributes to increasing crop productivity and improves the quality of agri-food products.

MATERIAL AND METHOD

Material and method. The research comprehensively analyzes existing literature studies, paying particular attention to studies addressing digitization methods used in agriculture.

The analytical and synthesis method of the information found in the specialized literature was used as a research method.

The selected articles and studies were identified in specialized journals, WOS, Scopus and Google Scholar and the selection period was from 1990 to the present. The search was carried out in Romanian using the keywords agriculture, digitization, digitization methods and in English using the keywords: digital, digitalization, agriculture.

RESULTS AND DISCUSSIONS

Results and discussions. The integration of digital technologies in agriculture has significantly contributed to the development of industrial agriculture (agriculture 4.0), which is also called smart agriculture or digital agriculture. Digital agriculture offers farmers a set of tools, shown in the figure below, so that they can address challenges regarding farm productivity, the impact of climate change on agricultural production, ensuring food security, crop losses and their sustainability (Abbsși *et al*, 2022).

The digitization of agriculture in Romania promises to significantly transform the way resources are managed and improve the sustainability of agricultural holdings. Modern technologies, such as ground sensors and satellite monitoring, provide essential data that enable accurate and efficient application of resources, reducing unnecessary consumption and optimizing productivity. This not only supports sustainable agriculture, but also contributes to rapid adaptation to climate change, preventing its negative effects through well-planned interventions.

Furthermore, innovations such as nanotechnologies open new perspectives for reducing the impact of chemicals on the environment, while blockchain guarantees the traceability of agri-food products, creating a transparent and reliable supply chain. However, the widespread adoption of these technologies is hampered by high costs and a lack of digital education, especially among small and medium-sized farmers. For Romania to fully capitalize on the benefits of digitization, an integrated approach that includes financial support, continuous training and collaboration between all actors in the sector is crucial.

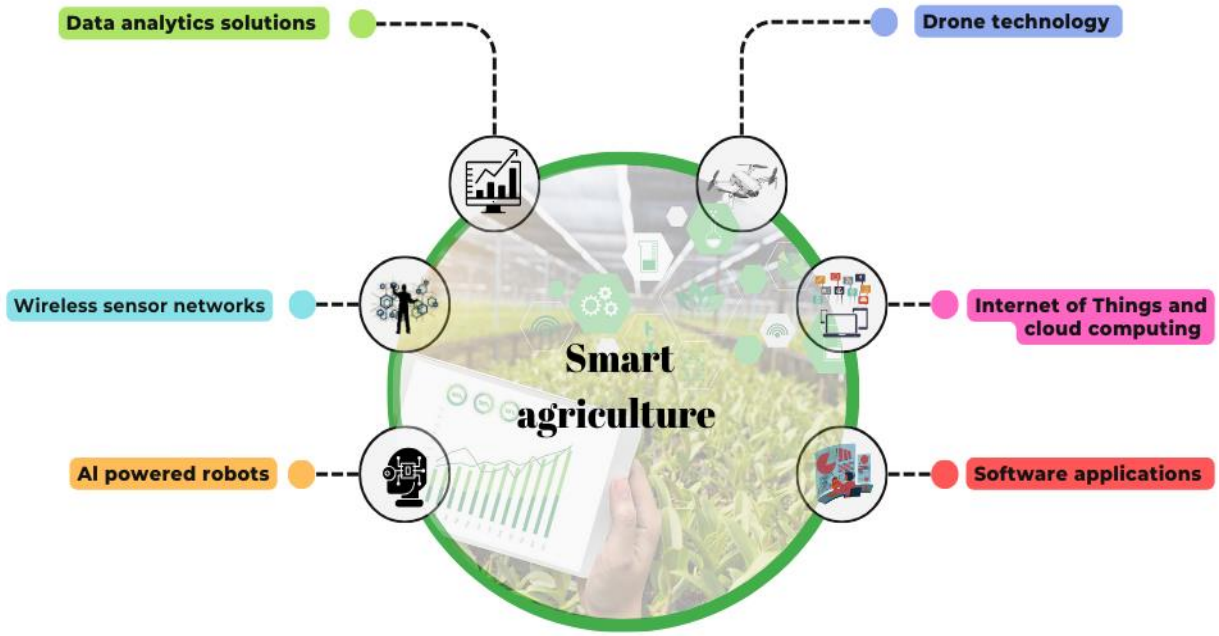

Figure 1 **. Digital Farming Toolkit**
Source: own processing, after Abbasi et al, (2022), using CANVA *application.*

Artificial intelligence (AI), machine learning, remote sensing, big data, blockchain technology (BCT) and the Internet of Things (IoT) are just some of the technologies that are revolutionizing agricultural value chains and modernization processes. Remote sensing, soil sensors, unmanned aerial surveys and market intelligence, among other technologies, enable farmers to collect, visualize and analyze crop and soil health parameters at different stages of production simply and cost-effectively. They can act as an early warning system, recognizing potential problems and providing real-time solutions to solve them (Javaid *et al*, 2022).

Despite the global accessibility of digital technologies, their adoption in the agricultural sector, especially among small and medium farms (family farmers), faces obstacles. Although it has been discussed for several years about the changes in the business models that come with these new technologies that define Agriculture 4.0 and the need to accelerate the transition. Shepherd, M. et al wrote in 2018 about the need to develop new skills and competencies (Shepherd *et al*, 2020).

Realizing the full potential of digital agriculture first requires understanding the factors influencing technology adoption (Fragomeli *et al*, 2024).

It can be stated that, unlike traditional agriculture, in precision agriculture, there are fundamental changes in the paradigm of agricultural production management, because, as a result of the robotization of production and the automation of production management systems, strategic decisions are made by humans and tactical decisions are made by machines based on displayed information (Homidov *et al*, 2024).

Digital innovations and artificial intelligence (AI) have a wide range of promising applications in the agricultural sector. Digital technologies can improve agricultural productions, both qualitatively and quantitatively, by using fewer production factors (water, energy, fertilizers and pesticides) and increase efficiency by performing agricultural practices remotely. Research shows that crop yields can increase significantly by 2050 with the introduction of precision agriculture technologies, with a yield increase of 18% due to precision fertilizer application, 13% due to precision planting, 4% due to precision spraying and 10 % thanks to precision irrigation. At the same time, the technologies practiced in precision agriculture allow for more efficient fertilization, adapted to the site, both with synthetic or mineral fertilizers and with manure. Fertilization based on soil needs is an essential starting point for avoiding nutrient surpluses. Thus, this directly contributes to meeting the objectives of the Nitrates Directive and the Water Framework Directive (Bahn *et al*, 2021; Garske *et al*, 2021).

One of the digitization methods identified in the specialized literature is represented by the Internet of Things (IoT) and Artificial Intelligence (AI). The Internet of Things is a network of physical objects called "things" with network connectivity that can enable these objects to collect and exchange data and at the same time interact with the environment. The application of this technology if supported by an intelligent and

efficient management system can lead to a significant reduction of human resources in various agricultural activities. AI algorithms can generate real-time actionable information to help farmers increase crop yields, control pests, aid in soil screening, provide farmers with accurate data and reduce their workload. The correlation of the Internet of Things with AI results in the development of much more efficient systems. AI-based systems represent computer systems that can perform operations that require human intervention (speech, visual perception, decision-making, as well as language translations) (Matta & Pant, 2019; Subeesh & Mehta, 2021; Javaid *et al*, 2022).

The AI-based IoT system has a very high potential to make agricultural operations more controlled and precise by introducing smart applications, shown in the figure below. The scope of recent advances in these technologies is endless in agricultural practices as it can automate complex tasks with minimal human intervention.

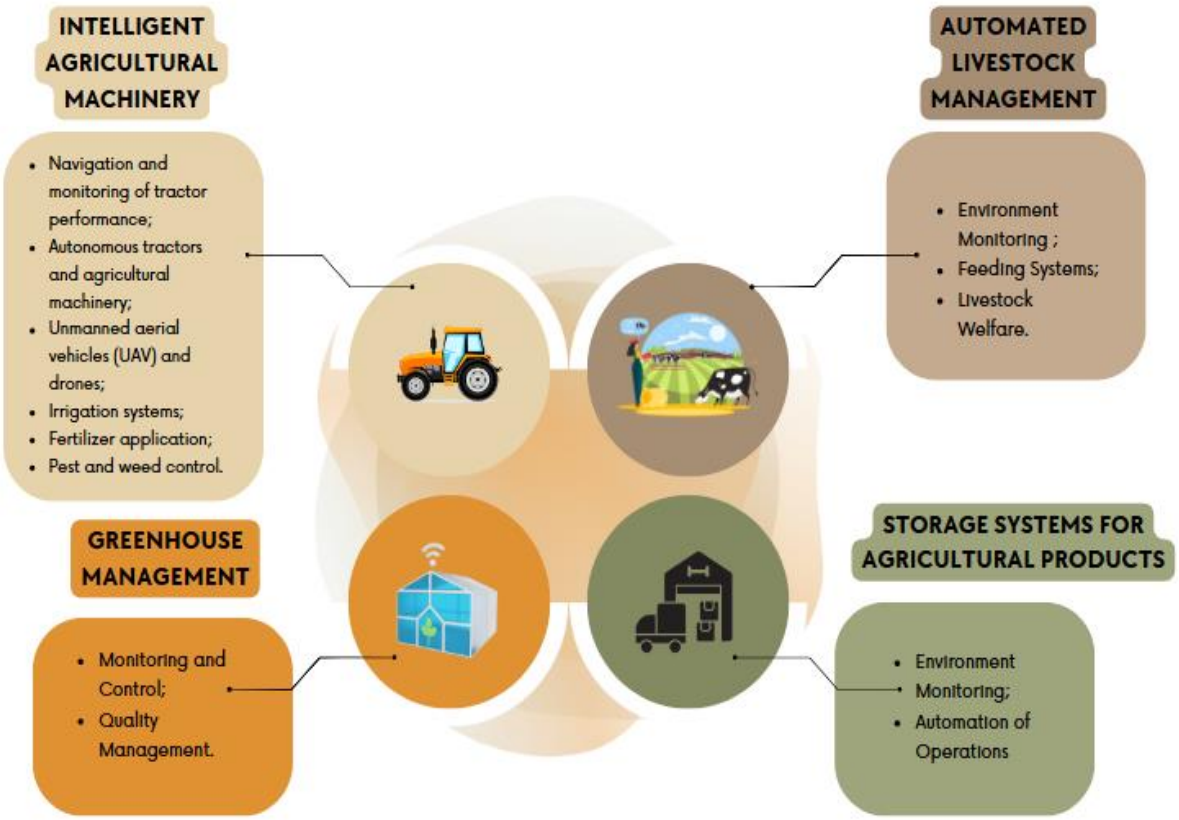

Figure **2 . Agricultural automation applications using IoT and AI**
Source: own processing after Subeesh & Mehta (2021), using CANVA application.

Another digitization method identified in the specialized literature is Blockchain Technology (BCT), a technology that has increased the confidence of both producers and consumers in the supply chain by providing truthful information on the quality of agri-food products.

Blockchain technology is a ledger of accounts and transactions that are written and stored by all the actors that take part in the agri-food chain, be it short or long. It allows access to transparent information, tracing the provenance of agri-food products by creating reliable agri-food supply chains aimed at strengthening a relationship of trust between producers and consumers. Additionally, used alongside smart tools, this technology enables real-time payments between interested actors that can be triggered by data changes occurring in the blockchain. Thus it can be stated that Blockchain technology can be applied in agriculture to improve food safety and transaction times (Chen *et al*, 2020).

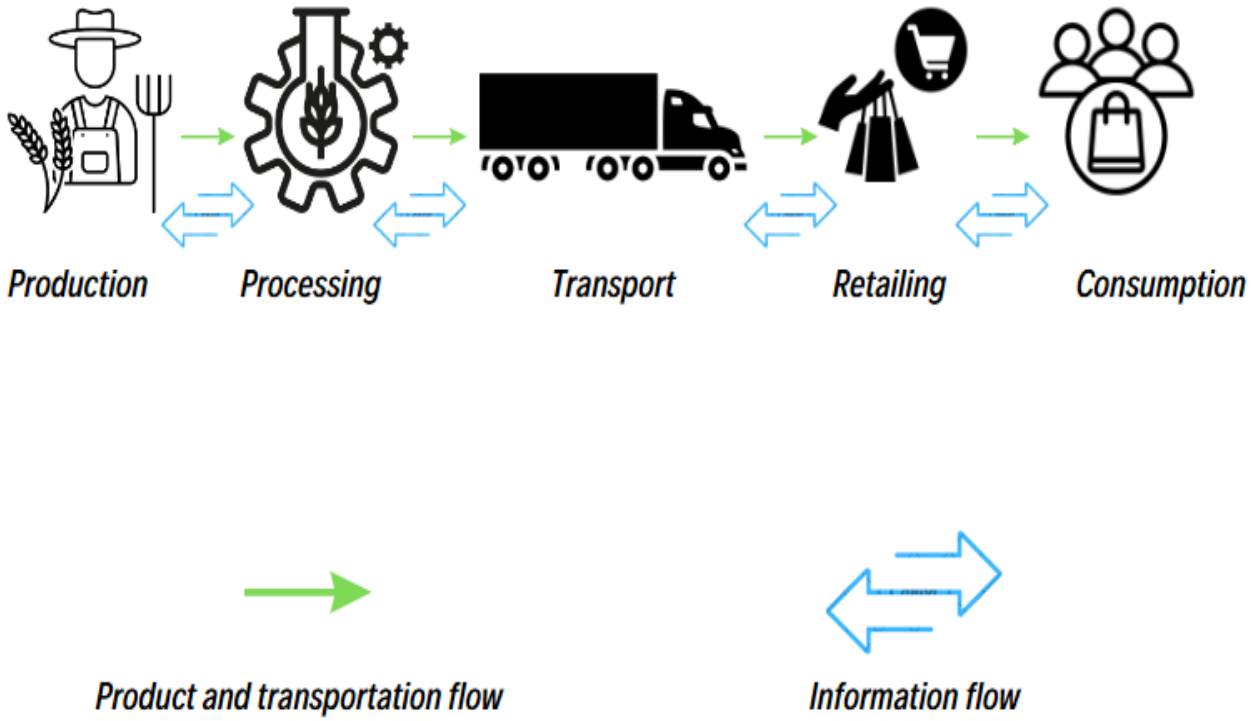

Figure **3 . Blockchain technology – the flow of products and information**
Source: own processing after Demestichas (2020), using the CANVA application.

Used together with the AI-based IoT system, blockchain technology can overcome several traceability issues and improve the transparency of the agri-food supply chain because it is plausible to keep chemical analysis data in chronological order, thereby eliminating data manipulation and falsification. From a supply chain and logistics perspective, blockchain technology has been valued for its visibility, immutability of transactions, and credibility among participating stakeholders (Rejeb *et al*, 2021).

Tabel 1

Digitization methods used at farm holding level

Digitization methods	Description
Precision agriculture - Optimal management	Decisions at the farm level are based on data obtained by IoT sensors and equipment used to develop a type of smart agriculture. State-of-the-art nanotools such as: nanofertilizers, nanopesticides, nanobiosensors and nanotechnology-based remediation techniques for polluted soils are being used to improve the yield and quality of agri-food products. Communication between hardware and sensors is used to automate agricultural decisions. Thus, autonomous robots have computer vision and learning algorithms to monitor crops and soil and perform predictive analytics to track and anticipate the influence of the environment on agricultural production. Smart agriculture emphasizes precision agriculture, the Internet of Things, and the use of big data to create improved economic efficiency in the face of population growth and climate change. Precision agriculture can significantly increase agricultural yields, enabling farms to become more efficient and sustainable. Through this agricultural practice, soil management is optimized using technology-based systems and tools, such as remote sensing and GPS (Ali et al. 2024). Thus, farmers can make better and more efficient decisions with the support of technologies, which can reduce farm expenses, increase profitability, reduce water wastage and help preserve soil quality.
Computer programs for soil composition analysis	The purpose of soil composition analysis is to help the farmer assess the level of nutrients in the soil. Drones, satellite imagery and computer software allow farmers to collect and harvest real-time crop data using tablets and mobile phones to help monitor crop health. This data is analyzed to develop insights that could improve overall production. More in-depth analysis helps farmers plan production from a given plot of land and monitor activity from seeding to harvest. Mining the voluminous data created by adopting information technology tools provides practical agricultural solutions that will improve the profitability, efficiency and sustainability of

	agricultural production. It creates a distributed and decentralized blockchain record of agricultural information that acts as a transparent and trusted source to improve agricultural supply chains. Thus, traceability options empower farmers and establish direct contact between farmers and customers.
Smart agricultural technologies that contribute to reducing the impact on the environment	Agricultural technologies such as blockchain, drones and IoT are resulting in increased yields, lower prices and a smaller environmental footprint. Farmers can use these technologies to grow new crops and increase their tolerance to extreme weather conditions and climate change. In this context, the agricultural sector will be better able to meet the demands of consumers of agri-food products and provide them with extensive information about each product with the help of smart technologies. Through smart harvesters, autonomous tractors and sensors that provide information on soil condition s and crops, digital agriculture has high potential to meet the environmental challenges of the coming decades. The development of a smart technology network and its goal-oriented use is a big challenge for farmers. IoT and digitalization in general offer improved control of agriculture and soil improvement. At the same time, the standards of traceability and transparency tend to increase recently, which makes it even more important to develop reliable and accurate tools to optimize agricultural production, while providing improved working conditions for farmers.
Smart agricultural technologies that contribute to combating crop diseases	Drones are already widely used in the agricultural sector to combat crop disease outbreaks, pest problems and efficient seeding. Studies have shown that in the last four years field robots have been used more and more frequently on farms, this trend appeared as an effect of the lack of labor during the pandemic. Because field robots can be used to move plants into greenhouses, check soil moisture, and apply automated pesticide sprays to infested crops, their popularity is expected to grow in the coming years. Solar pumping, cooling and drying are examples of practices that help farms adopt, develop and implement cost-effective marketing solutions for agricultural production, post-harvest processing and storage. For farmers and implicitly for agricultural holdings, technologies have the direct effect of reducing costs and achieving higher yields. The technologies not only bring direct benefits to farmers and their farms, but also generate jobs, currency and economic growth along the supply chain until the products reach the end consumers.
Smart agricultural technologies that ensure secure transactions and food tracking	Blockchain technology enables accurate and tamper-proof data about farms and stocks, as well as fast and secure transactions and food tracking. As a result, farmers no longer rely on documents or files to capture and store data. The implementation of these technological solutions allows for more reliable agricultural management and monitoring. Farmers can act accordingly after receiving an in-depth digital analysis of their crops in real time, eliminating the need to apply unnecessary pesticides and fertilizers and reducing overall water use.

Source: processing after Javaid et al, (2022).

CONCLUSIONS

Conclusions. In recent years, digitization methods in the agricultural sector have benefited from increasing popularity among farmers, given the current situation of agriculture, which is faced with an increase in demand for agri-food products, an increasing consumption of natural resources combined with the negative effects of climate change. In this context, digital agriculture can represent a solution for all these challenges, because it contributes to increasing the productivity of crops, improves the managerial process, reduces the impact on the environment by making the use of resources more efficient. From a climate point of view, digital agriculture can lead to reducing the effects of climate change by reducing greenhouse gas emissions. The integration of digital technologies in agriculture has led to the development of agriculture 4.0, also known as smart or digital agriculture, which provides farmers with a set of modern tools to address challenges related to productivity, climate change, food security, etc. Technologies such as artificial intelligence, remote sensing, blockchain and the Internet of

Things (IoT) play an important role in modernizing agriculture and improving the efficiency of this sector.

However, the adoption of these technologies faces obstacles, especially among small and medium-sized farms, and it is necessary to understand the factors that influence this adoption. Conclusions reached by Giorgio A et al. in a recent study carried out in a region of Italy, proposing a better awareness of the need to invest in human resources to develop the digital skills of farmers in order to optimally use new technologies (Giorgio A et al., 2024) Precision agriculture allows optimizing resources through the efficient use of fertilizers, water and pesticides, thus contributing to the achievement of sustainability goals.

IoT and AI-based systems have the potential to automate and streamline agricultural operations, reducing the need for human intervention and increasing crop yields. In addition, blockchain technology helps increase

trust in the agri-food supply chain, providing transparency and food safety.

The combined use of digital technologies has the potential to fundamentally transform agriculture, facilitating the transition to more productive, sustainable and resource-efficient agriculture.

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REFERENCES

Abbasi R., Martinez P., & Ahmad R., 2022 - *The digitization of agricultural industry–a systematic literature review on agriculture 4.0.* Smart Agricultural Technology, 2, 100042.

Atkočiūnienė V., & Papšienė P., 2023 - *Opportunities for digitisation of agricultural and rural development solutions.* Management theory and studies for rural business and infrastructure development, 45(1), 1-8.

Bahn R.A., Yehya A.A.K., Zurayk R., 2021 - *Digitalization for sustainable agri-food systems: potential, status, and risks for the MENA region.* Sustainability, 13(6), 3223.

Chen Y., Li Y., Li C., 2020 - *Electronic agriculture, blockchain and digital agricultural democratization: Origin, theory and application.* Journal of cleaner production, 268, 122071.

Demestichas K., Peppes N., Alexakis T., Adamopoulou E., 2020 - *Blockchain in agriculture traceability systems: A review.* Applied Sciences, 10 (12), 4113.

Everitt J.H., Escobar D.E., Villarreal R., Noriega J.R., & Davis M.R., 1991 - *Airborne video systems for agricultural assessment.* Remote Sensing of Environment, 35(2-3), 231-242.

Fragomeli R., Annunziata A., & Punzo G., 2024 - *Promoting the Transition towards Agriculture 4.0: A Systematic Literature Review on Drivers and Barriers.* Sustainability, 16(6), 2425.

Garske B., Bau A., Ekardt F., 2021 - *Digitalization and AI in European agriculture: a strategy for achieving climate and biodiversity targets?* Sustainability, 13(9), 4652.

Homidov H., Penev N., Azimov D., Maxmudov A., & Nencheva I., 2024 - *Prospects of the introduction of digital technologies in agricultural activities.* In BIO Web of Conferences (Vol. 114, p. 01005). EDP Sciences.

Javaid M., Haleem A., Singh R. P., Suman R., 2022 - *Enhancing smart farming through the applications of Agriculture 4.0 technologies.* International Journal of Intelligent Networks, 3, 150-164.

Javaid M., Haleem A., Singh R.P., Suman R., & Gonzalez E.S., 2022 - *Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability.* Sustainable Operations and Computers, 3, 203-217.

Matta P., & Pant B., 2019 - *Internet of things: Genesis, challenges and applications.* Journal of Engineering Science and Technology, 14(3), 1717-1750.

Meghișan-Toma G.M., & Nicula V.C., 2020 - *Possible Use of ICT in Agriculture for a Sustainable Development*. New Trends in Sustainable Business and Consumption, 1287.

Meng J., Zhao B., Song Y., & Lin X., 2024 - *Research on the Spatial Dynamic Evolution of Digital Agriculture—Evidence from China*. Sustainability, 16(2), 735.

Zhao B., Song Y., & Lin X., 2024 - *Research on the Spatial Dynamic Evolution of Digital Agriculture—Evidence from China.* Sustainability, 16(2), 735.

Pătărlăgeanu S.R., Constantin M., Dinu M., Petrescu I. E., & Deaconu E.M., 2024 - *Farm Carbon Footprint Measurement Frameworks Based on the Digitization and Environmental Sustainability Paradigm.* In Proceedings of the International Conference on Business Excellence (Vol. 18, No. 1, pp. 1602-1612).

Rejeb A., Rejeb K., Abdollahi A., Zailani S., Iranmanesh M., Ghobakhloo M., 2021 - *Digitalization in food supply chains: A bibliometric review and key-route main path analysis.* Sustainability, 14(1), 83.

Rodino S., Buțu M., Buțu A., Lazăr C., Ciornei L., & Simion P.S., 2023 - *Challenges of Digital Transformation in Agriculture from Romania.* Rom. Agric. Res, 40, 713-721.

Simo A., Dzitac S., Badea G.E., & Meianu D., 2022 - *Smart agriculture: IoT-based greenhouse monitoring system*. International Journal of Computers Communications & Control, 17(6).

Subeesh A., Mehta C.R., 2021 - *Automation and digitization of agriculture using artificial intelligence and internet of things.* Artificial Intelligence in Agriculture, 5, 278-291.

Giorgio A., Penate Lopez L.P., Bertoni D., Cavicchioli D., Ferrazzi G., 2024 - *Enablers to Digitalization in Agriculture: A Case Study from Italian Field Crop Farms in the Po River Valley, with Insights for Policy Targeting.* Agriculture, 14(7):1074. https://doi.org/10.3390/agriculture14071074

Gaber K., Rösch C., & Bieling C., 2024 - *Digital transformation of fruit farming in Germany: Digital tool development, stakeholder perceptions, adoption, and barriers.* NJAS: Impact in Agricultural and Life Sciences, 96(1). https://doi.org/10.1080/27685241.2024.2349544

Shepherd M., Turner J.A., Small B. and Wheeler D. 2020 - *Priorities for science to overcome hurdles thwarting the full promise of the 'digital agriculture' revolution.* J. Sci. Food Agric., 100: 5083-5092. https://doi.org/10.1002/jsfa.9346

Ali A; Hassan MU; Kaul HP, 2024 - *Broad Scope of Site-Specific Crop Management and Specific Role of Remote Sensing Technologies Within It-A Review*. Journal of Agronomy and Crop Science, 210(4).